How innovative flexible polyurethane adhesives can improve bonding connections in wooden structures – experiences from two European projects and other research

INTERNATIONAL CONFERENCE ON WOOD ADHESIVES
FOCUSING ON THE INTERSECTION OF SUSTAINABILITY & AI

FLEX AND ROBUST SYSTEMS

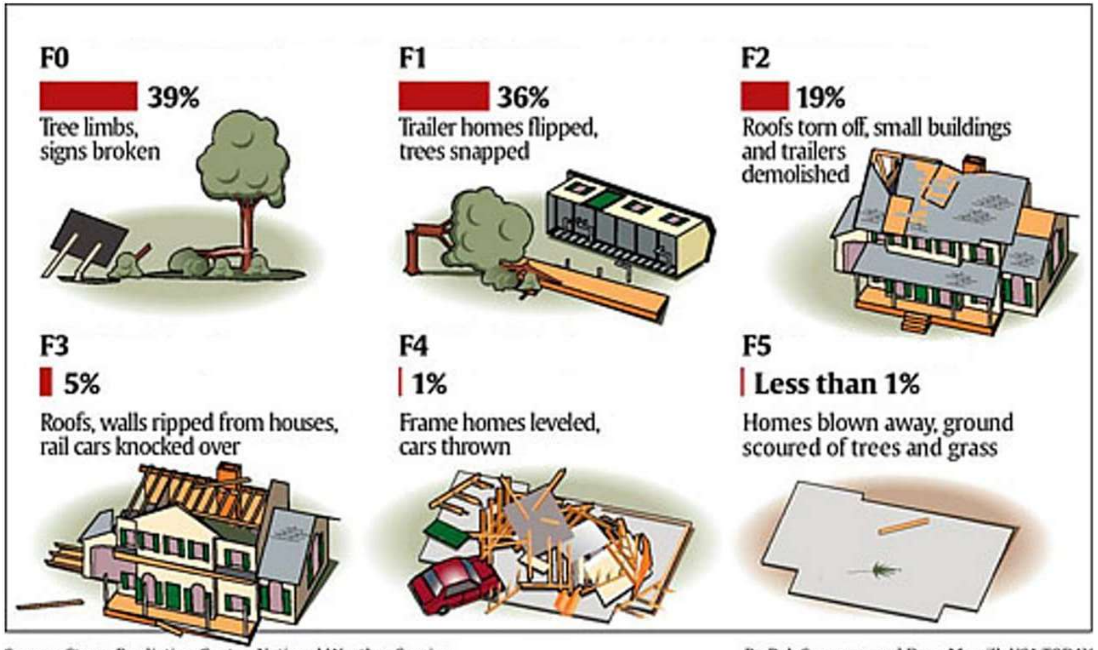
Arkadiusz Kwiecień
(Poland)

Cracow University of Technology
80th Anniversary

MEZeroE project is a project receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 953157.

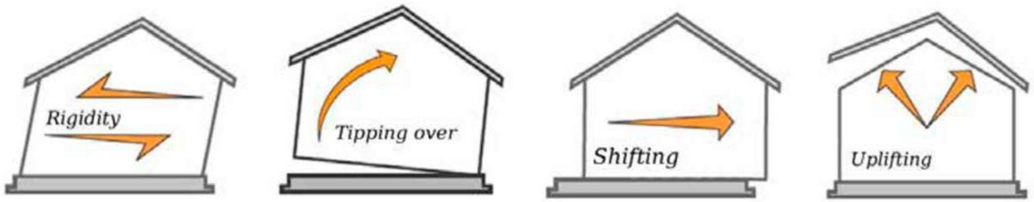
DIAMONDS - "DIAgnostics and Mechanical tests Of aged adhesive layers used in joiNts of wooDen structureS",
Funded by the National Science Centre, Poland under the OPUS call in the Weave program,
No. 2021/43/I/ST8/00554

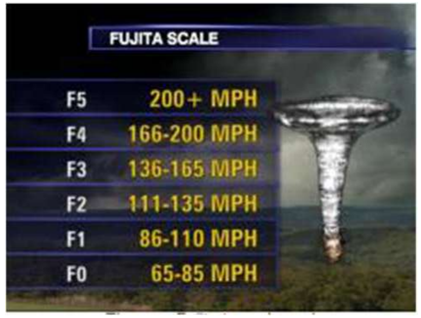
Catastrophic influences on buildings – tornados and hurricanes



Source: Storm Prediction Center, National Weather Service

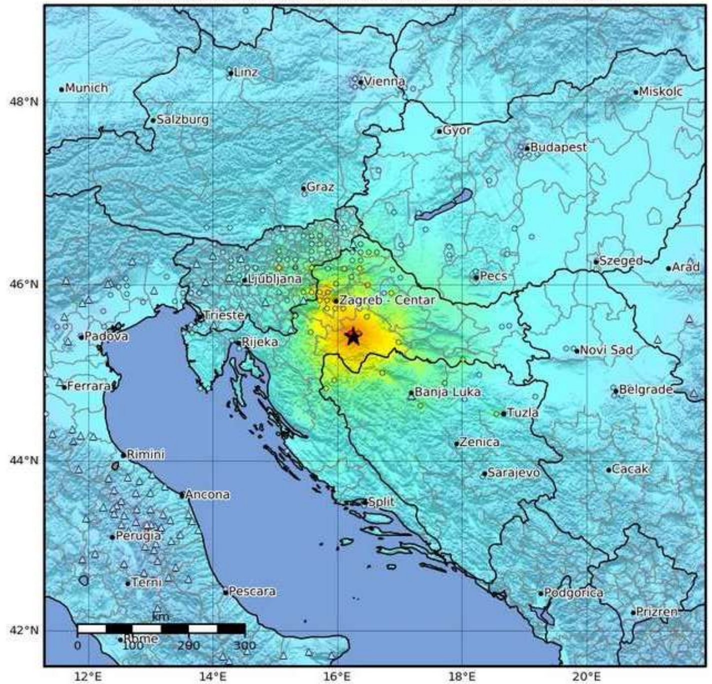
By Bob Swanson and Dave Merrill, USA TODAY





2020 Petrinja earthquake (29 December 2020)

Macroseismic Intensity Map USGS
ShakeMap: 3 km WSW of Petrinja, Sisačko-Moslavačka, HR
Dec 29, 2020 11:19:54 UTC M6.4 N45.42 E16.26 Depth: 10.0km ID:us6000d3zh



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 4: Processed 2020-12-30T11:21:46Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Solutions resistant to seismic and strong wind loads causing stress concentration and large deformations

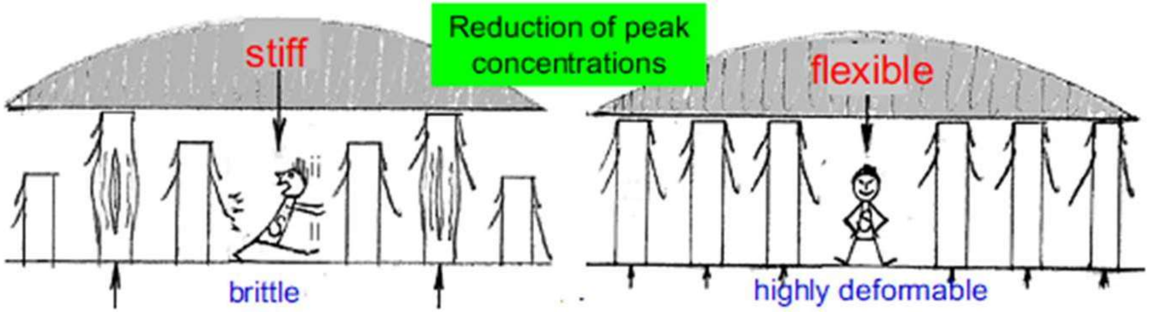
Proven experimentally by shake table tests!

PUFJ - PolyUrethane Flexible Joints

Deformable structural connectors transferring high loads and high deformations

FRPU - Fiber Reinforced PolyUrethanes

Deformable adhesives and composite matrices dissipating energy

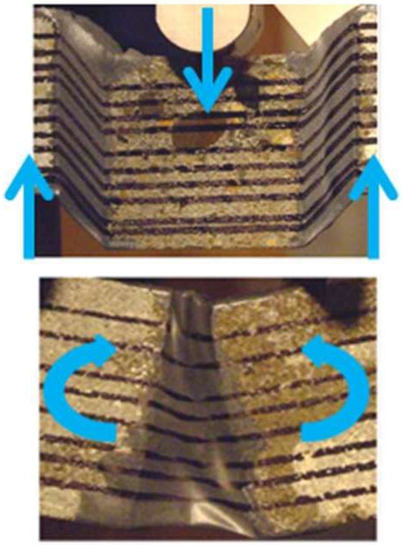


stress concentration

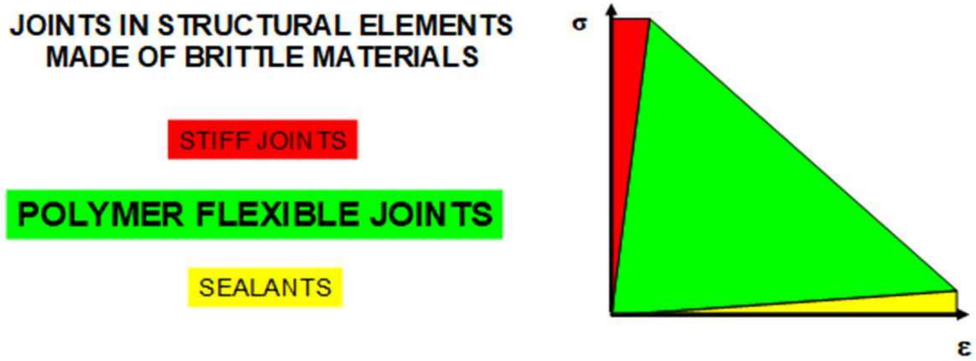
even stress redistribution

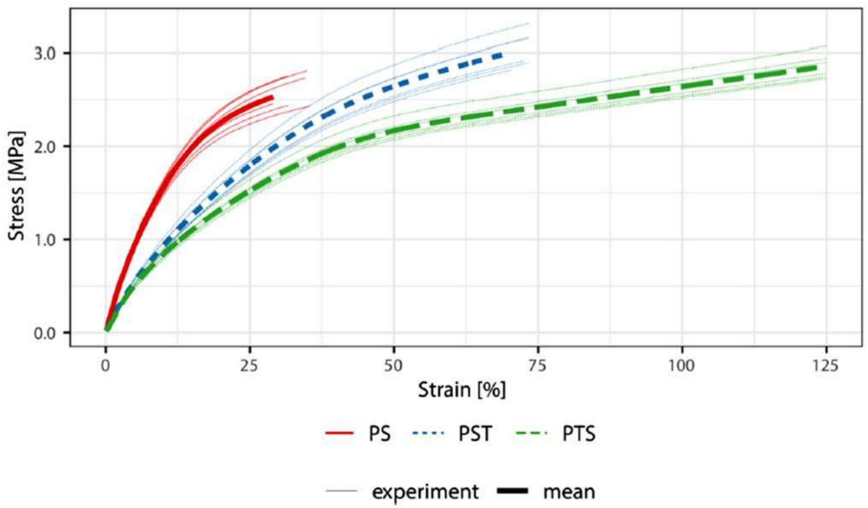
MEZeroE

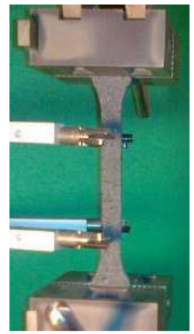
Polyurethanes using for PUFJ and FRPU of non-linear characteristic



PUFJ and FRPU transfer
high loads and large deformations
simultaneously



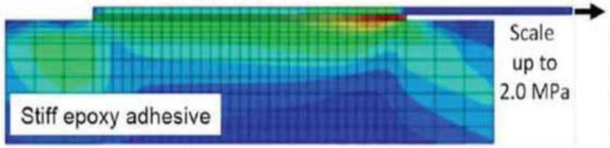




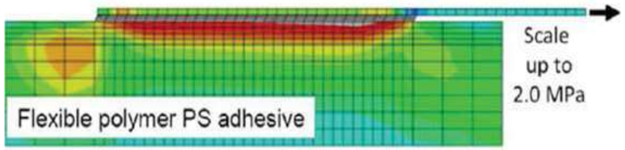
Composite strengthening of structural element single-lap shear test

- *Stiff or flexible adhesive layer in shear?*

Stiff epoxy adhesive

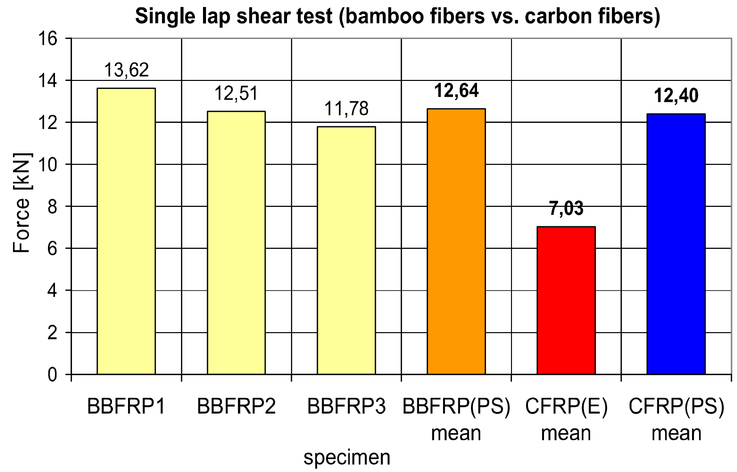


Flexible PU adhesive



stress concentration

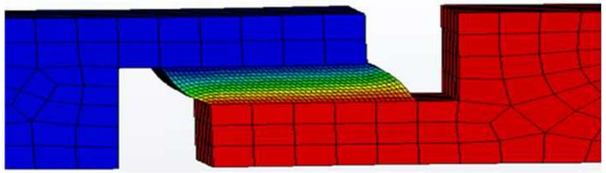
even stress redistribution



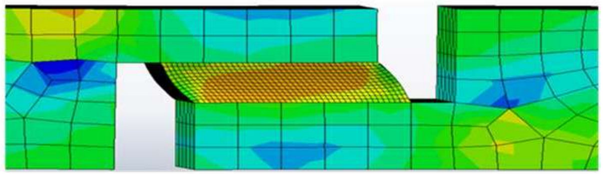
Almost even stress distribution in thick flexible joint

Shear failure mode

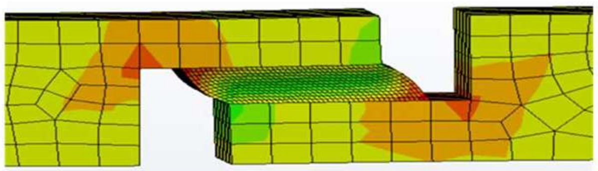
Nonlinear displacement

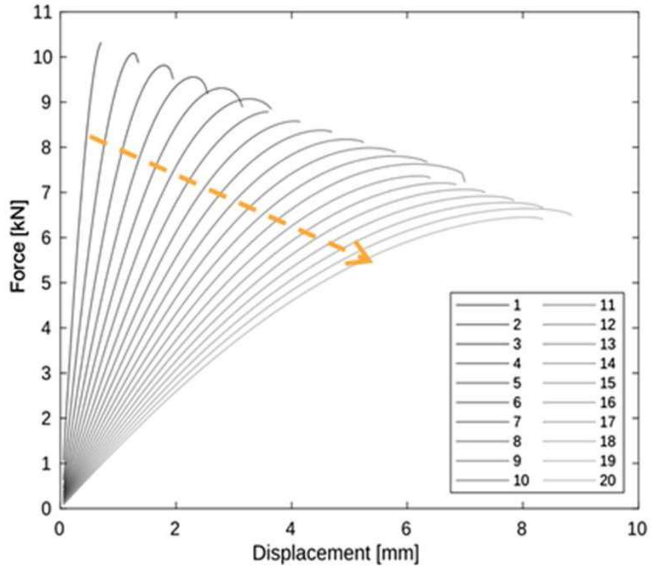


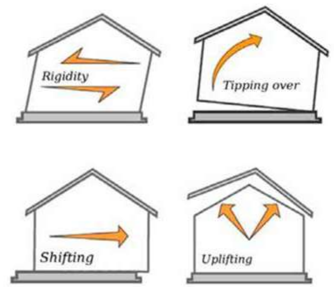
Shear stress



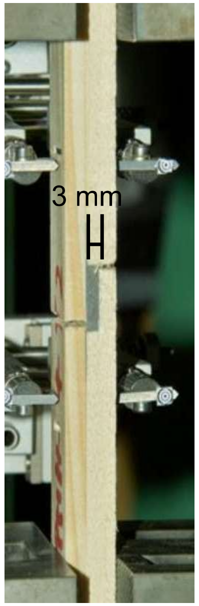
Normal stress

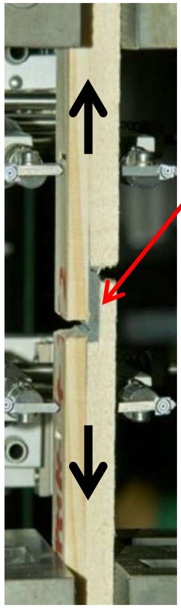






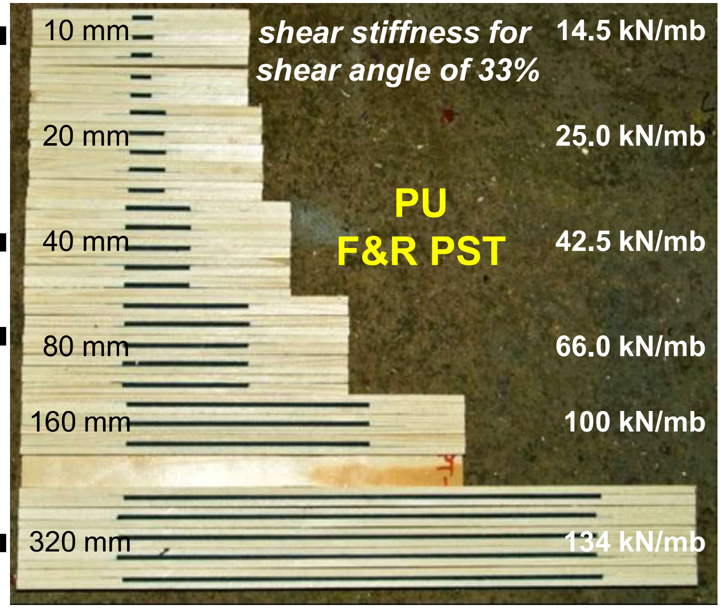
Bonding length influence on load capacity in flexible adhesives





τ_{max} = 2,5 MPa

γ_{max} = 100 %

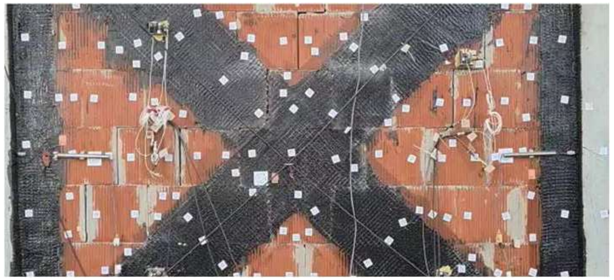


Failure of polymer in short connections

Failure of timber in long connections

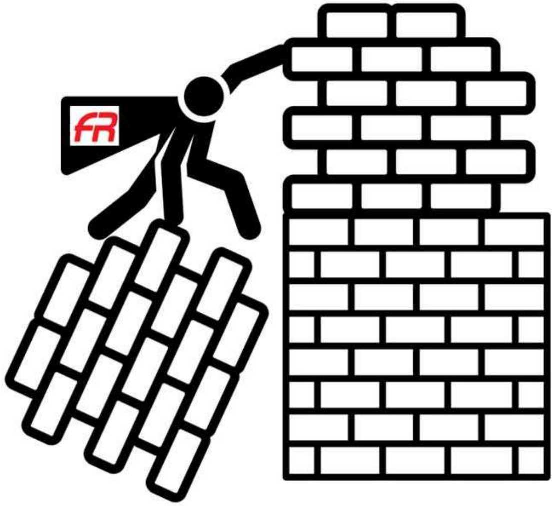
Deformable structural connectors
transferring high loads and high deformations

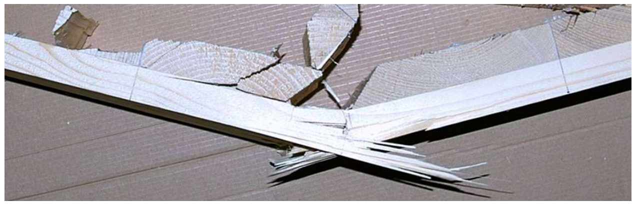
PUFJ



FRPU

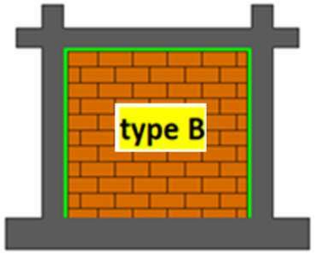
Deformable adhesives and composite matrices
dissipating energy





EARTHQUAKES AND STRONG WINDS DO NOT KILL PEOPLE, BUILDINGS DO

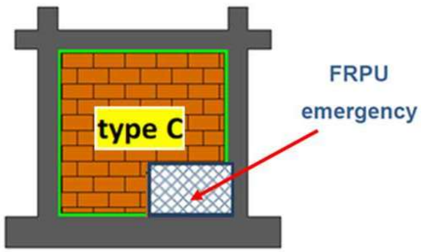
PUFJ injected at 3 edges



Global stiffness decrease 100% --> 6% after in-plane test

PUFJ_IN protected infill against falling out

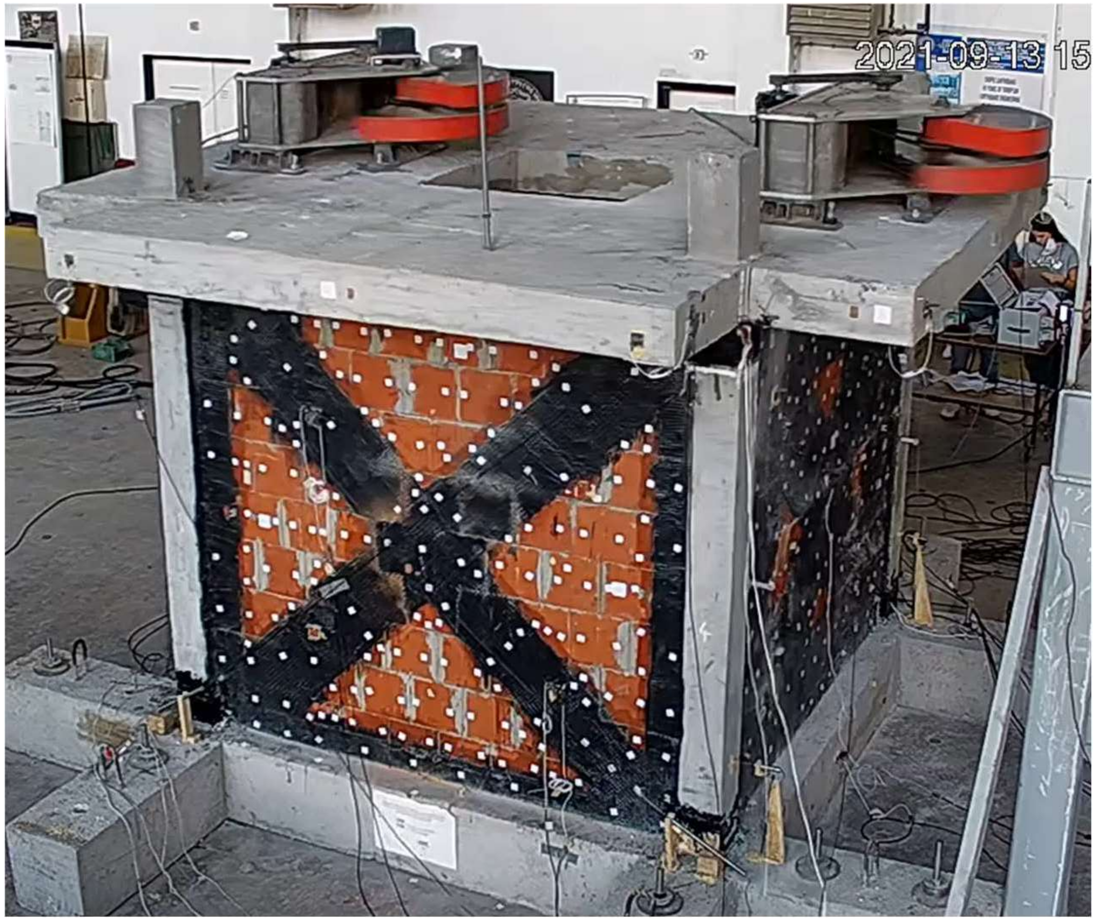
FAR products recovered stiffness and resistance

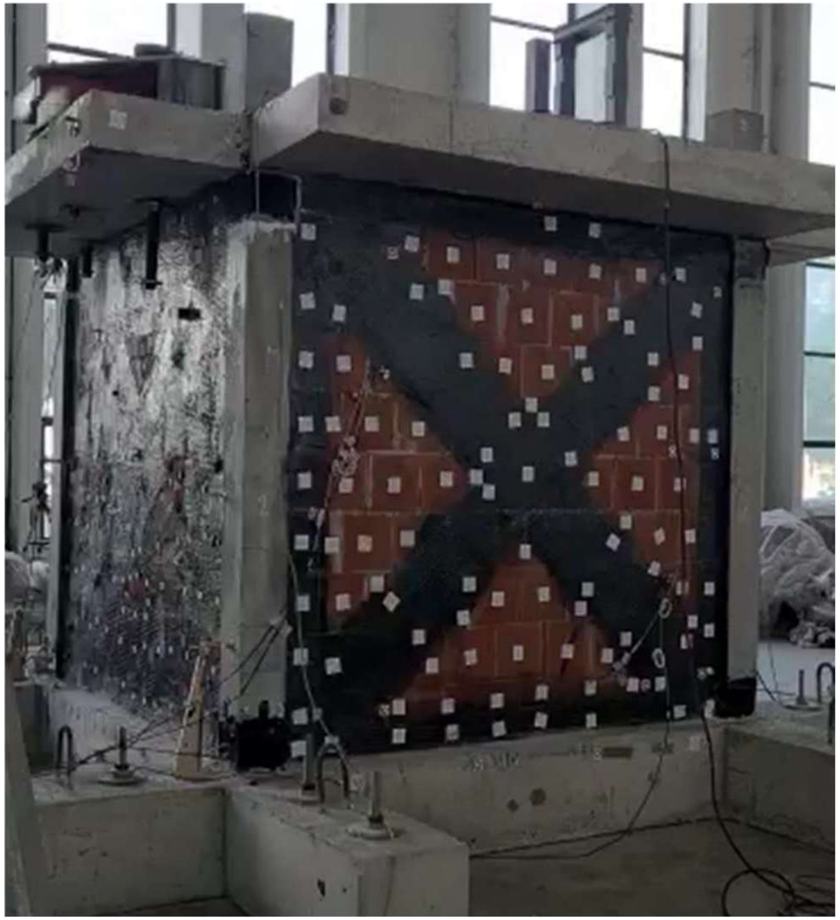


Global stiffness increase
21% --> 77%

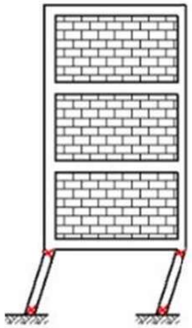
PUFJ_PR and FRPU made strong infill

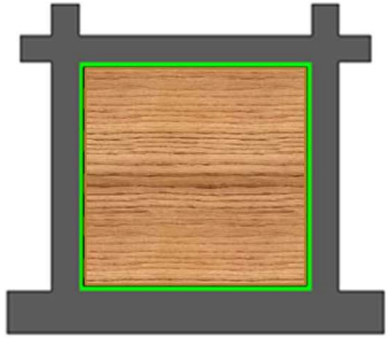
Force vibration test after the shake table tests in IZIIS

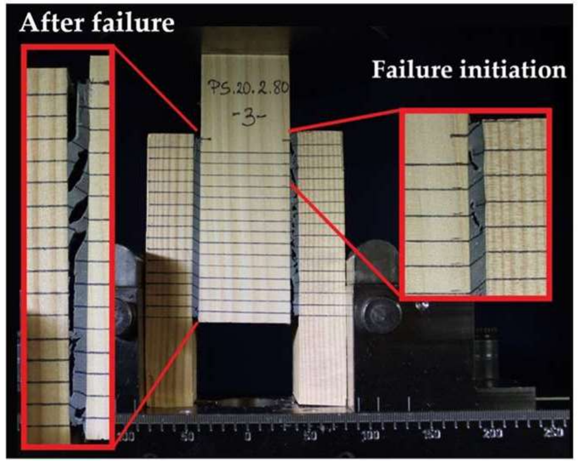




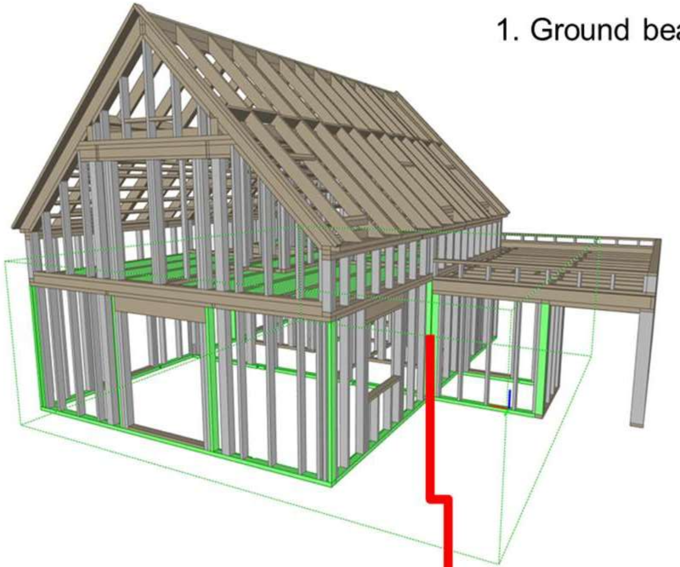
Protection against „soft story" failure



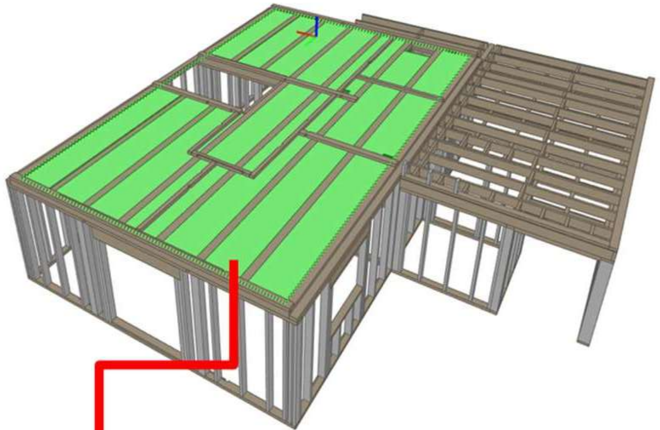




Real implementation of PUFJ in a timber house

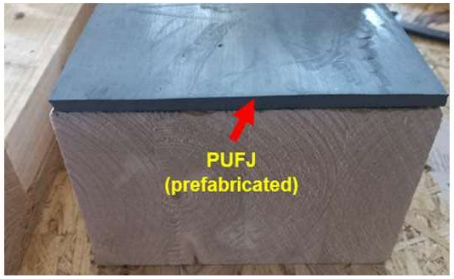


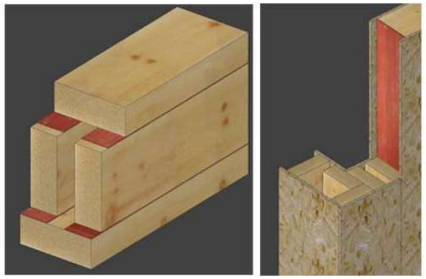
1. Ground beams bonded by polyurethane flexible adhesives

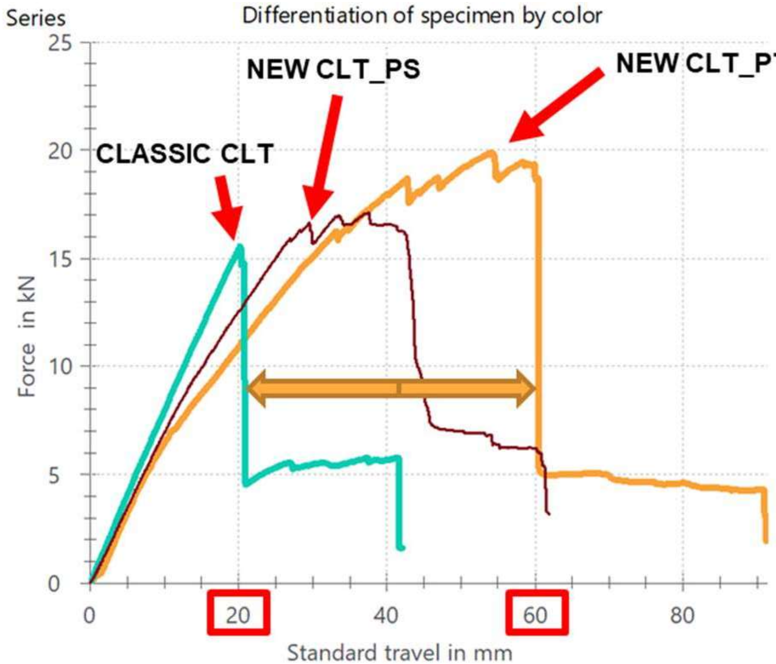


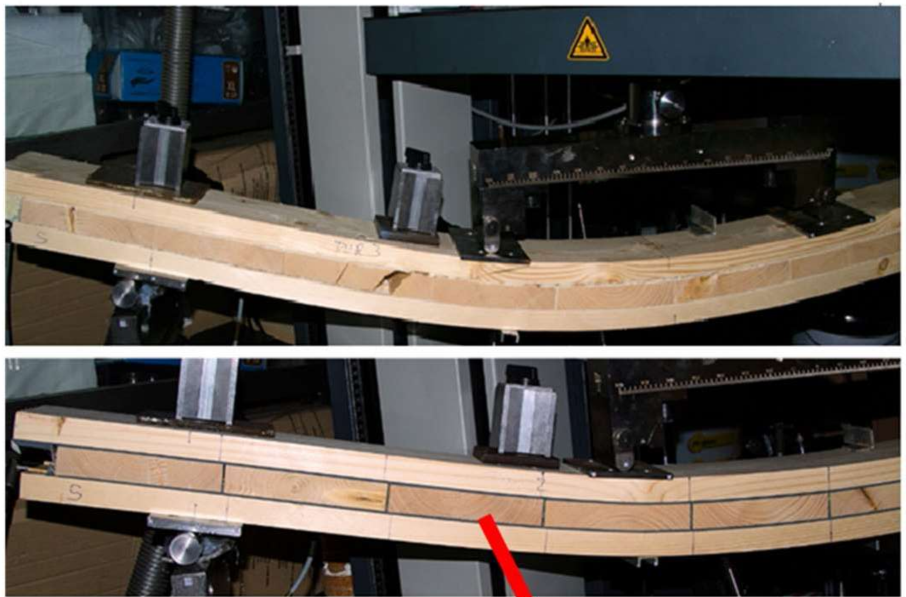
3. New CLT ceiling slabs bonded by polyurethane flexible adhesives

2. Walls bonded by polyurethane flexible adhesives



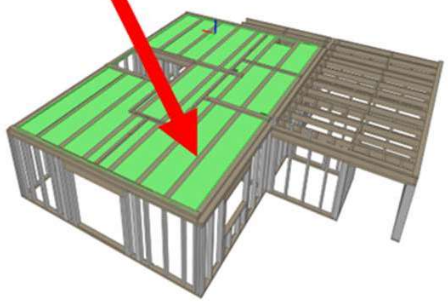






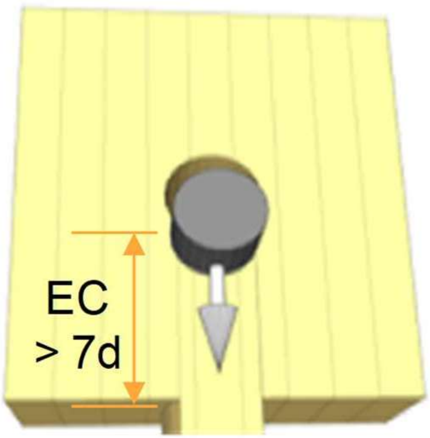
Stiff PUR adhesive

Flexible PUFJ adhesive



Stress concentrations in wooden elements (caused by steel dowels)

Local damage around a steel dowel

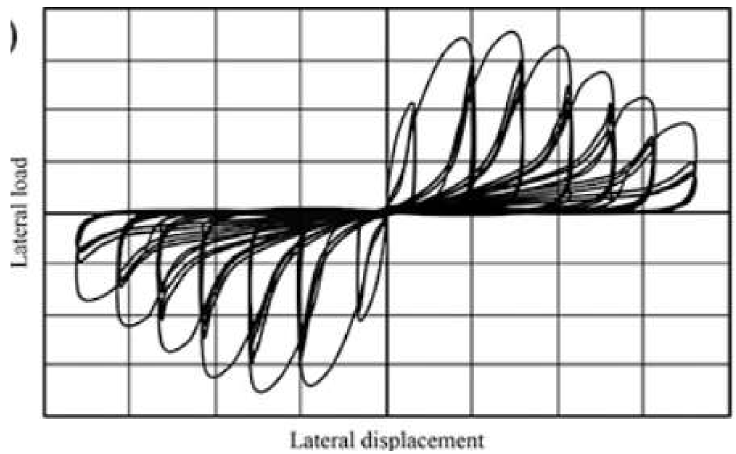


Larsson G.: HIGH CAPACITY TIMBER JOINTS. Proposal of the shear plate dowel joint. Lund University. ISBN 978-91-7753-107-4,

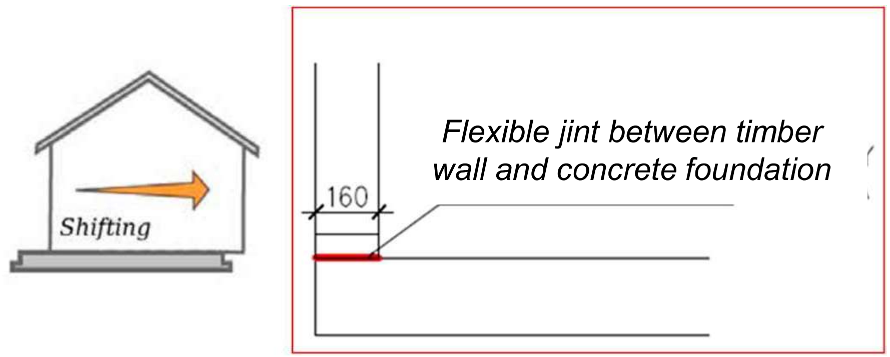
Damage of a timber element caused by a steel dowel

Valluzzi M.R., Garbin E., Modena C., Bozza E., Francescato D.: Modeling of timber floors strengthened with seismic improvement techniques. Wiadomości Konserwatorskie • Journal of Heritage Conservation • 46/2016, pp 69-79,

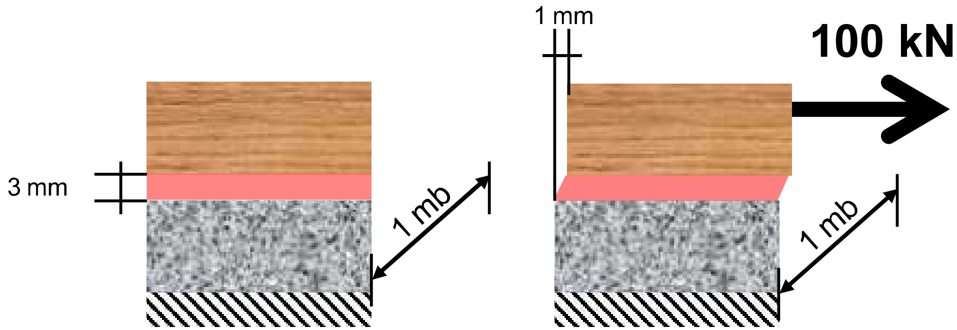
Resistance to cyclic loads



Porcu M.C.: Ductile Behavior of Timber Structures under Strong Dynamic Loads. Chapter 9. Engineering » "Wood in Civil Engineering", book edited by Giovanna Concu, ISBN 978-953-51-2986-8, Print ISBN 978-953-51-2985-1, Published: March 1, 2017



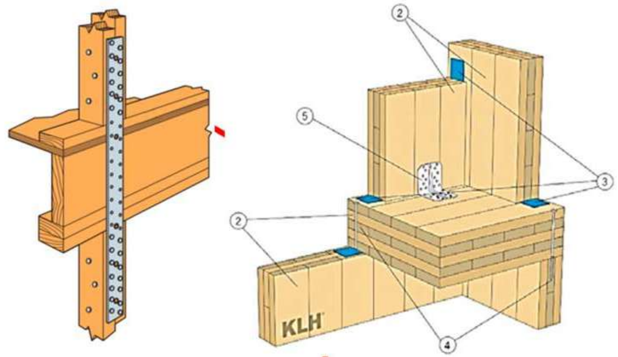
Min-juan H., Hui-fen L.: Comparison of glulam post-to-beam connections reinforced by two different dowel-type fasteners. Construction and Building Materials. Volume 99, 30 November 2015, Pages 99-108

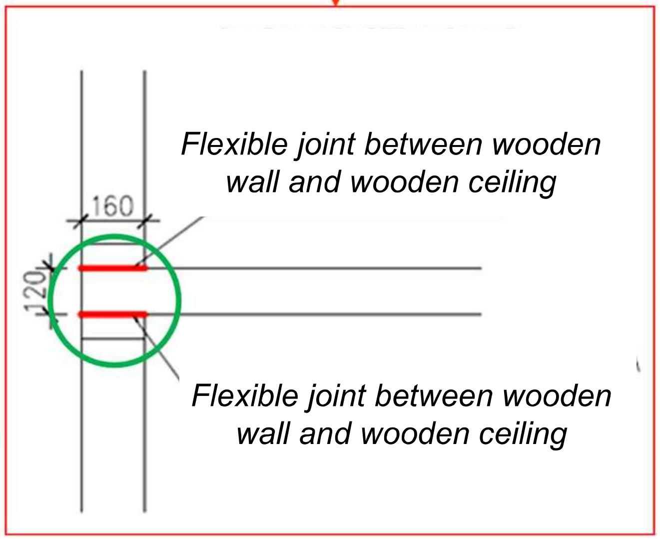


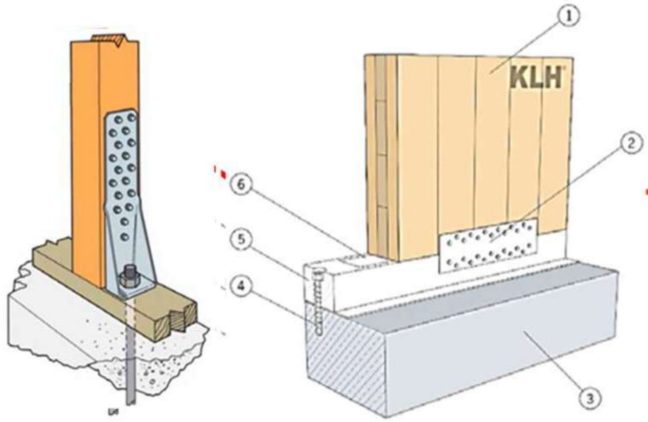
Hybrid connections: steel dowels - flexible polyurethane adhesives

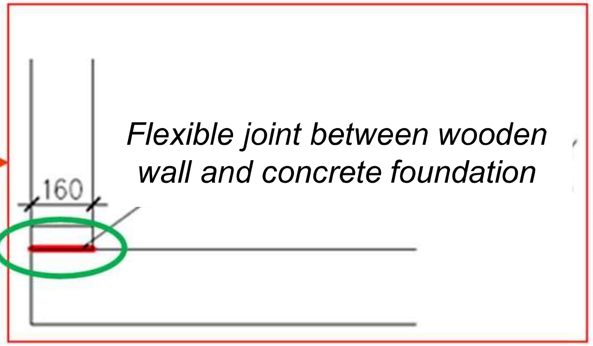
New flexible polyurethane adhesive:

- *blocks the transfer of moisture and thermally insulates from the ground*
- *enables quick assembly and disassembly (by a saw) of elements made of various materials*
- *ensures tightness of connections along their entire length*
- *ensures stability of deformation properties under cyclic loads*



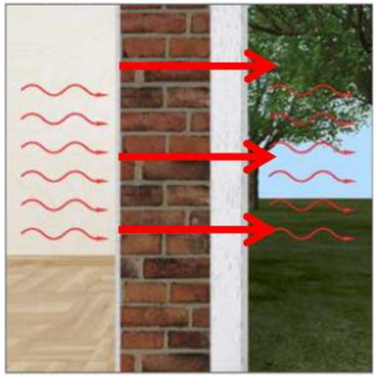






Hydro-thermal protection against vapor and heat transfer

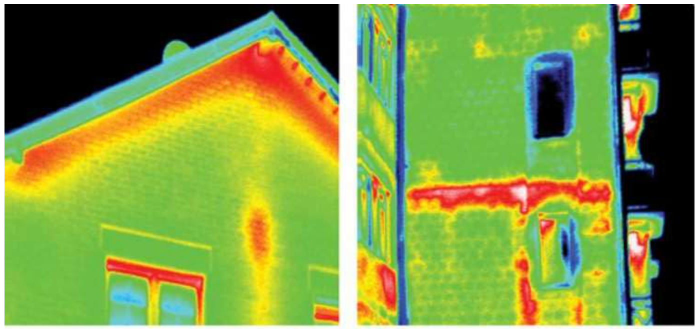
Vapor and heat transfer



Polyurethane F&R PM - vapor barrier (can protect wood)

- water vapor permeability $w_p = 7.38 \cdot 10^{-11}$ kg/(m$^2 \cdot$s$\cdot$Pa)
- water vapor diffusion resistance factor μ = 294

Thermal video camera



Avoiding of thermal bridges

Material samples	Thermal conductivity coefficient λ [W/(mK)]	The volume heat capacity x 10^3 C_v [kJ/(m^{3}K)]
Wood	0.1157	1.3595
PM soft polymer	0.1013	0.7418

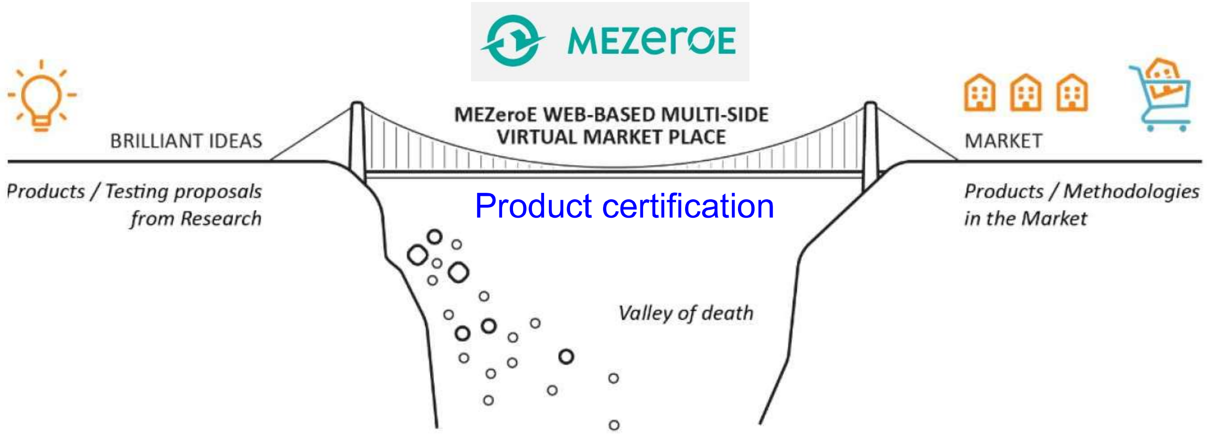
MEZeroE project - virtual market place for innovative products in nZEB envelopes

HORIZON 2020

Measuring Envelope products and systems contributing to next generation of healthy nearly Zero Energy Buildings

EUROPEAN COMMISSION
Directorate-General for Research and Innovation
RTD.F – Prosperity
F.4 – Materials for Tomorrow

Technical requirements	Requirements categories under EU Regulation 305/11	Requirements implementation
Safety	Mech. resistance and stability	Statics, durability, Seismic resistance
	Safety in case of fire	Reaction to fire, fire resistance, propagation
	Safety and accessibility in use	Building as a safe to use system
Health	Hygiene, health, environment	High IEQ, water tightness, vapour permeability
	Protection against noise	Airborne sound insulation, soundscape, vibration
Efficiency	Energy economy, heat retention	nZEB, SRI, air permeability
	Sustainable use of nat. sources	GPP, envelope circular economics



https://www.mezeroe.eu/

MEZeroE

Measuring Envelope systems
for Zero Energy buildings

SERVICE PROVIDERS

- eurac research
- POLITECNICO MILANO 1863
- LEITAT managing technologies
- universität innsbruck
- ZAG
- Cracow University of Technology
- ITeC
- Danmarks Tekniske Universitet DTU
- tecnalia
- compáz

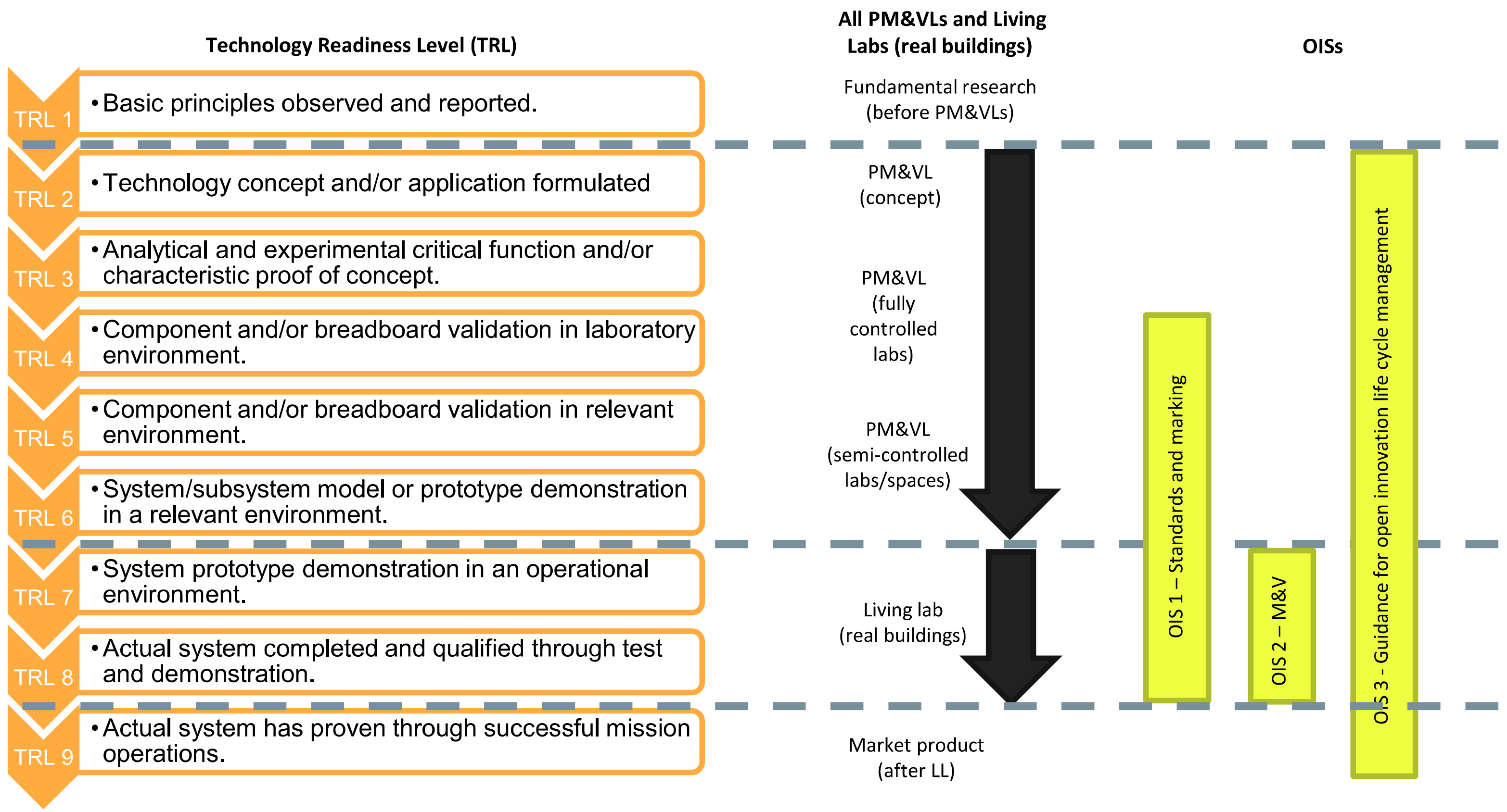
INDUSTRIAL PARTNERS

- FOCCHI SINCE 1914
- VELUX
- WindowMaster Fresh Air. Fresh People.
- Flexbrick
- Heliatek INDEPENDENT. GREEN. FUTURE.
- TECNAN TECNOLOGIA NAVARRA DE NANOPRODUCTOS, S.L.
- FLEX AND ROBUST
- rothoblaas Solutions for Building Technology
- RIKO Riko Hiše
- INDRESMAT INDUSTRIAL RESINS & MATERIALS
- arbnco
- greenTEG
- Nuvap
- Pellini

MEZeroE project is a project receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 953157.


MEZeroE
Measuring Envelope systems for Zero Energy buildings
Join the community
OPEN INNOVATION DIGITAL PLATFORM FOR ZERO ENERGY BUILDING ECOSYSTEM
www.mezeroe-platform.eu
© Tecnalia
© UIBK
© Tecnalia
© DTU
© ZAG
© Eurac
© RIKO Hiše
© Focchi

Procedure steps at the MEZeroE platform



MEZeroE

PMVL1

Safety, performance and efficiency characterization of BIPV and hybrid PV/T systems

This line is dedicated to photovoltaic and hybrid photovoltaic/thermal modules. It allows the measurement of their performances in controlled lighting conditions by using a sun simulator and by recording results at different angles of incidence. It makes it possible to measure modules in real outdoor conditions and to contrast them with the indoor equivalents, which allows the closest possible predictive data. With PMVL 1, the behavior of these modules can also be tested in case of fires that might occur because of an overheat or a default in the electrical system. With a focus on the safety of the occupants, it indicates how the modules and their components (glass, polymers, etc.) will behave when they burn. Potential risks – burning residue from melting polymers, breaking glass, electrical arcs, etc. – can be assessed and remedied.

PMVL 2

Building envelope/IEQ (Indoor Environmental Quality) interaction facing health requirements

This line has been designed to measure the performance of a façade building element (including windows) to measure its U-value performance, which refers to its capacity to keep or transmit heat flow and its insulating capability. It can also measure the acoustic performance of the façade elements. By quantifying these thermal and acoustic performances, it leads to solutions that offer more comfort to a building's occupants. In addition, this line is equipped to make chemical analyses of the organic volatiles, with their potential health risks, that can be emitted by these materials.

PMVL 3

Reliability of BIPV products, using accelerated tests for stability and quality of materials/products for outdoor use

This pilot line complements PMVL 1. It provides an infrastructure to test BIPV systems in conditions which replicate – to the greatest extent possible – their real-world equivalents. It allows our industrial partners to understand how their PV products will behave over the years in terms of electrical efficiency, based on how and where they are installed in a building.

PMVL 4

Dynamic glass systems facing efficiency requirements. A set of experimental and analytical tools to validate the performance of newly developed dynamic glazing elements

This pilot line is dedicated to window manufacturers. It makes it possible for them to understand precisely how their dynamic glass will behave in terms of light comfort and the insulation properties of the glass. It also ensures that these characteristics align with international standards.

PMVL 5

Building/user interaction characterization facing efficiency requirement

This line is squarely focused on IoT and AI tools that could be introduced in support of the occupants' comfort. It is designed to assess and control certain parameters of the quality of the indoor environment and the behavior of the inhabitants.

PMVL 6

Multilayer dry nEESs (nZEB Enabler Envelope Solutions) characterization facing Health and Safety requirement

This line provides an infrastructure to test materials at different scales. Considering the material itself, it offers, for example, an understanding of its resistance to impact. But it also makes it possible to examine – on a large scale – entire façade elements with tests that are ever-closer to the conditions they will face in the real world. From this series of measurements, some predictive modelling can be calculated and offered as important feedback for the manufacturers, helping them to improve their products.

PMVL 7

Testing of connections in envelopes

This line is specialized in testing the connection or adhesion between two different materials like, for example, the glue between two layers in a sandwich panel, the glue inside a PV module, or a window joint. Among other things, it tests the solidity of a glue and its intrinsic properties while aging, which helps us understand how these crucial elements will behave and last throughout the years.

PMVL 8

Enables a full-scale performance evaluation of the thermal and optical characteristics as well as comfort criteria of transparent, multi-functional facade elements

The PMVL 8 line is focused on testing transparent materials like window and glass façade elements. It has been conceived to evaluate the thermal and visual performances and comfort of the people living and working inside the building.

PMVL 9

Fire safety, hygro-thermal and acoustic characterisation of wooden-based prefab façade systems

This line, which is specifically dedicated to wood-based materials, tests their behavior when they are exposed to fire and humidity. It also considers the occupants' exposure to sound and to the acoustic characteristics of the materials.

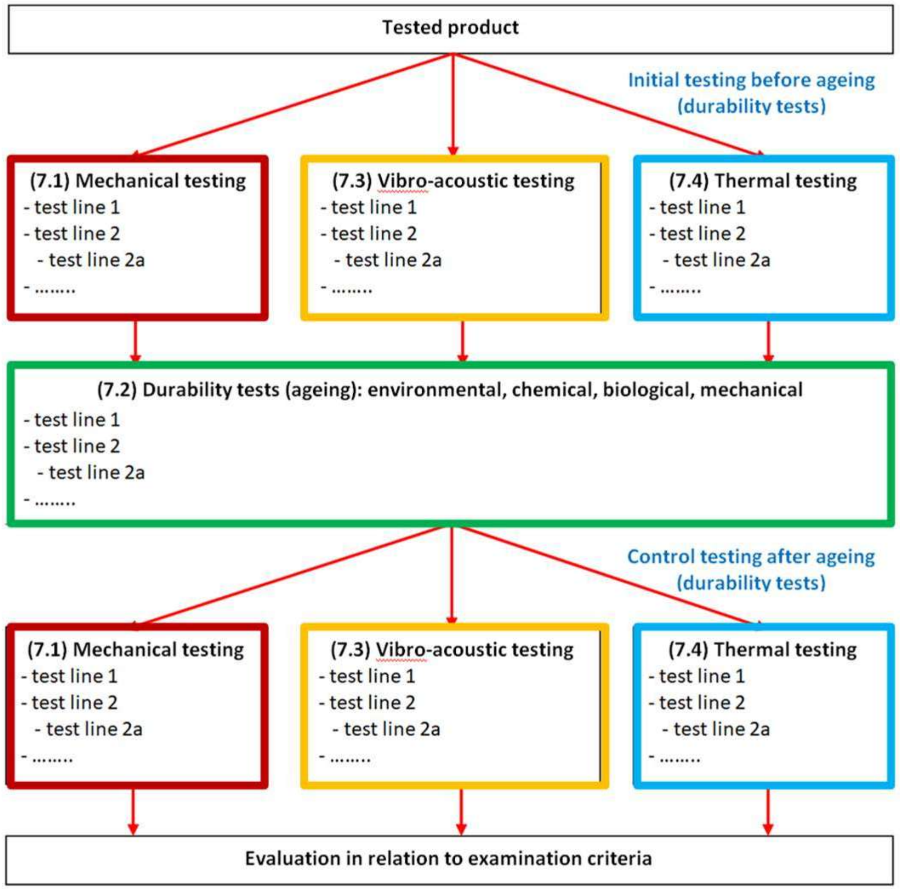
Pilot Measurements & Verification Lines (PM&VL)

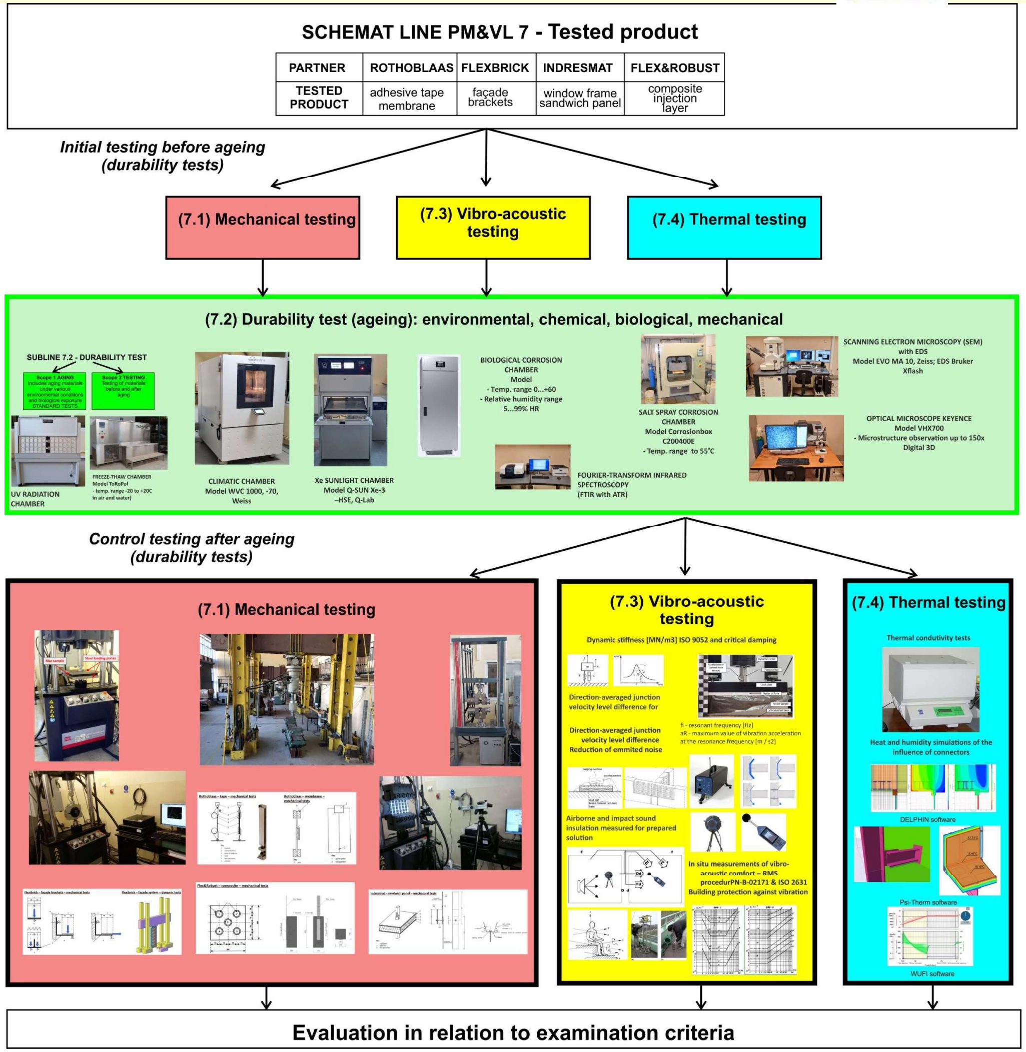
Item	Leading partner
PM&VL1	Tecnalia
PM&VL2	Eurac
PM&VL3	Leitat
PM&VL4	Leitat
PM&VL5	DTU
PM&VL6	PoliMI
PM&VL7	CUT
PM&VL8	UIBK
PM&VL9	ZAG

How innovative flexible polyurethane adhesives can improve bonding connections in wooden structures – experiences from two European projects and other research - A. Kwiecień

PM&VL7 | CUT

Cracow University of Technology





Symbol	Product	Subline	Test	WP3.4*
FRC	Flex&Robust composite	(7.1)	Breaking force /reference mechanical test before artificial aging/glass fibre grid	12
		(7.1)	Matrix tensile strength and modulus of elasticity /reference mechanical test before artificial aging/ polyurethane PS	2
		(7.1)	Composite tensile strength and modulus of elasticity - warp direction /reference mechanical test before artificial aging/ PS reinforced with glass fibre grid	4
		(7.2)	Artificial ageing behaviour before durability test - Observation in optical microscope and in scanning microscope SEM	22 i 23
		(7.2)	Artificial ageing behaviour before durability test - Testing FTIR	24
		(7.2)	Durability - sunlight Xe	19
		(7.1)	Mechanical test after artificial ageing - Breaking force - glass fibre grid	12
		(7.1)	Mechanical test after artificial ageing -Matrix tensile strength and modulus of elasticity polyurethane PS	2
		(7.1)	Mechanical test after artificial ageing -Composite tensile strength and modulus of elasticity - warp direction PS reinforced with glass fibre grid	4
		(7.2)	Artificial ageing behaviour after durability test - FTIR	24
		(7.2)	Artificial ageing behaviour after durability test - Observation in optical microscope or in scanning microscope SEM	22 i 23
		(7.2)	Durability - see water or breeze	18
		(7.1)	Mechanical test after artificial ageing -Composite tensile strength and modulus of elasticity - warp direction PS reinforced with glass fibre grid	4
		(7.1)	Dynamic stiffness /modulus of composite - warp direction	15
		(7.3)	Critical damping ratio [%]	25
		(7.3)	Dynamic stiffness (MN/m3)	28
		(7.3)	Airborne and impact sound insulation measured for prepared solution	26
		(7.3)	Direction-averaged junction velocity level difference for connector or for connection model	27
		(7.4)	Water vapour diffusion (Interstitial water vapor condensation risk and intensity);	29
		(7.4)	Internal surface temperature	30
		(7.4)	Linear thermal transmittance (iii)	31

Tested Flex&robust Composite in PM&VL_7

Flex&Robust Composite
FRPU – Fiber Reinforced PU
(Fibers in PU matrix)

Tests Flex&robust Injection in PM&VL_7

Symbol	Product	Subline	Test	WP3.4*
FRI	Flex&Robust injection	(7.1)	Initial shear strength	9
		(7.2)	Artificial ageing behaviour before durability test - Observation in optical microscope and in scanning microscope SEM	22 i 23
		(7.2)	Artificial ageing behaviour before durability test - Testing FTIR	24
		(7.2)	Durability - sunlight Xe	19
		(7.2)	Artificial ageing behaviour after durability test - FTIR	24
		(7.2)	Artificial ageing behaviour after durability test - Observation in optical microscope or in scanning microscope SEM	22 i 23
		(7.3)	Critical damping ratio [%]	25
		(7.3)	Dynamic stiffness (MN/m3)	28
		(7.3)	Airborne and impact sound insulation measured for prepared solution	26
		(7.3)	Direction-averaged junction velocity level difference for connector or for connection model	27
		(7.4)	Water vapour diffusion (Interstitial water vapor condensation risk and intensity);	29
		(7.4)	Internal surface temperature	30
		(7.4)	Linear thermal transmittance (iii)	31

Flex&Robust Injection
PUFJ - PU Flexible Joint
(Injected PU)

Tests Flex&robust Layer in PM&VL_7

Symbol	Product	Subline	Test	WP3.4*
FRL	Flex&Robust layer	(7.1)	Tensile strength and modulus of elastiicity /reference mechanical test before artificial aging/	11
		(7.2)	Artificial ageing behaviour before durability test - Observation in optical microscope and in scanning microscope SEM	22 i 23
		(7.2)	Artificial ageing behaviour before durability test - Testing FTIR	24
		(7.2)	Durability - sunlight Xe	19
		(7.1)	Mechanical test after artificial ageing - Tensile strength and modulus of elastiicity	11
		(7.2)	Artificial ageing behaviour after durability test - FTIR	24
		(7.2)	Artificial ageing behaviour after durability test - Observation in optical microscope or in scanning microscope SEM	22 i 23
		(7.3)	Critical damping ratio [%]	25
		(7.3)	Dynamic stiffness (MN/m3)	28
		(7.3)	Airborne and impact sound insulation measured for prepared solution	26
		(7.3)	Direction-averaged junction velocity level difference for connector or for connection model	27
		(7.4)	Water vapour diffusion (Interstitial water vapor condensation risk and intensity);	29
		(7.4)	Internal surface temperature	30
		(7.4)	Linear thermal transmittance (iii)	31

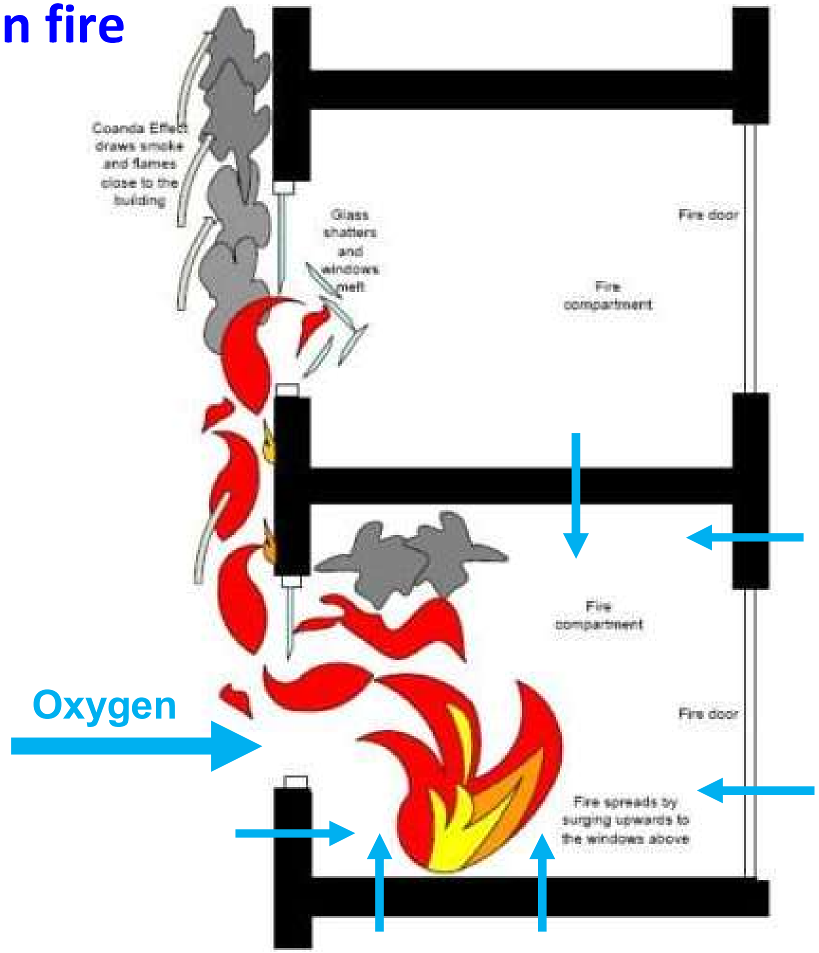
Flex&Robust Layer
PUFJ - PU Flexible Joint
(Prefabricated PU)

Lack of tightness – problem in fire

Injected

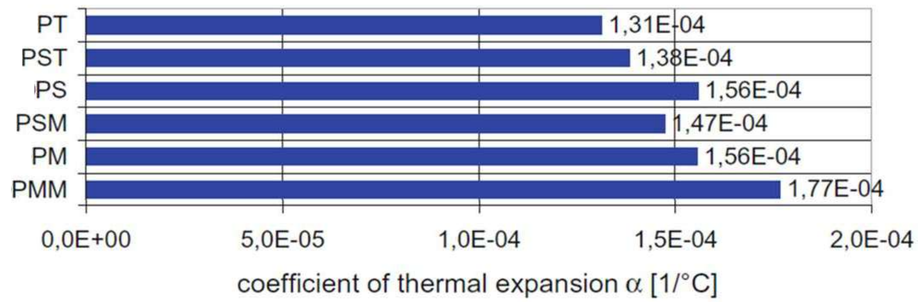
Prefabricated

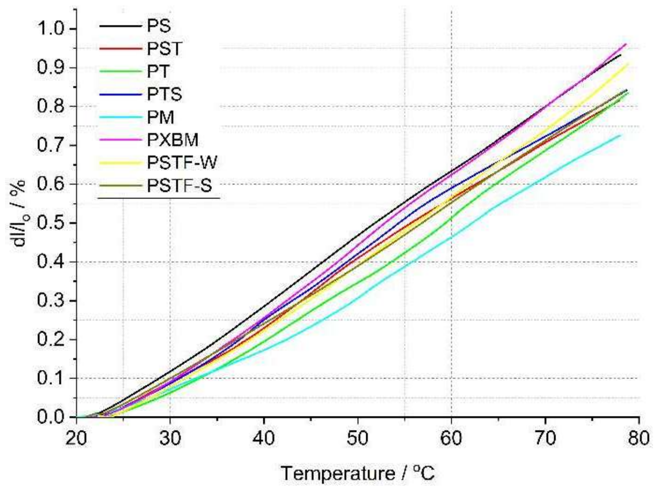
Min-juan H., Hui-fen L.: Comparison of glulam post-to-beam connections reinforced by two different dowel-type fasteners. Construction and Building Materials. Volume 99, 30 November 2015, Pages 99-108



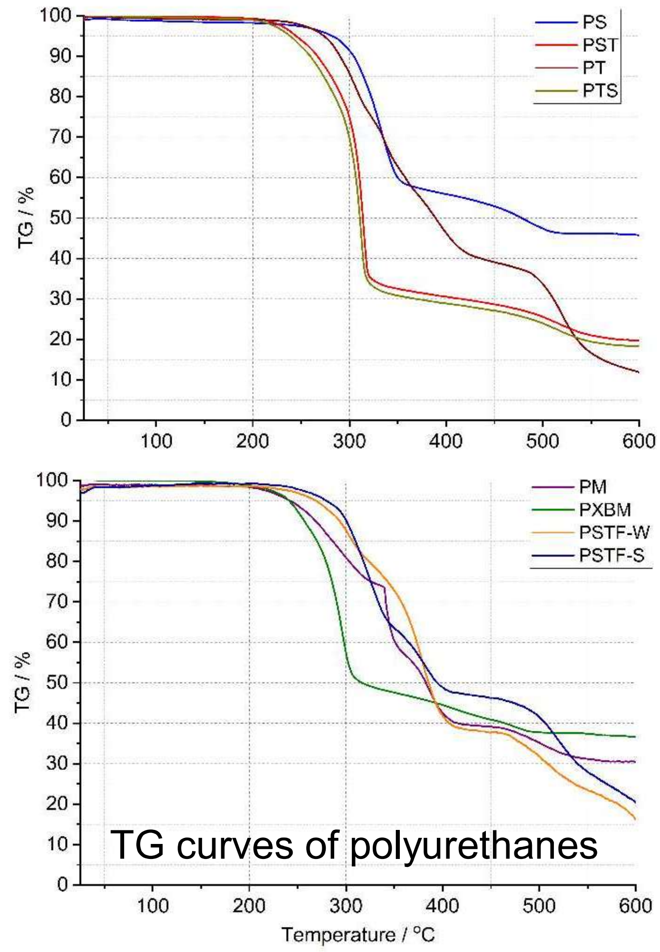
http://pensher-skytech.com/opinion-piece-grenfell-tower/

Thermal stability of flexible (polyurethane F&R P) adhesives



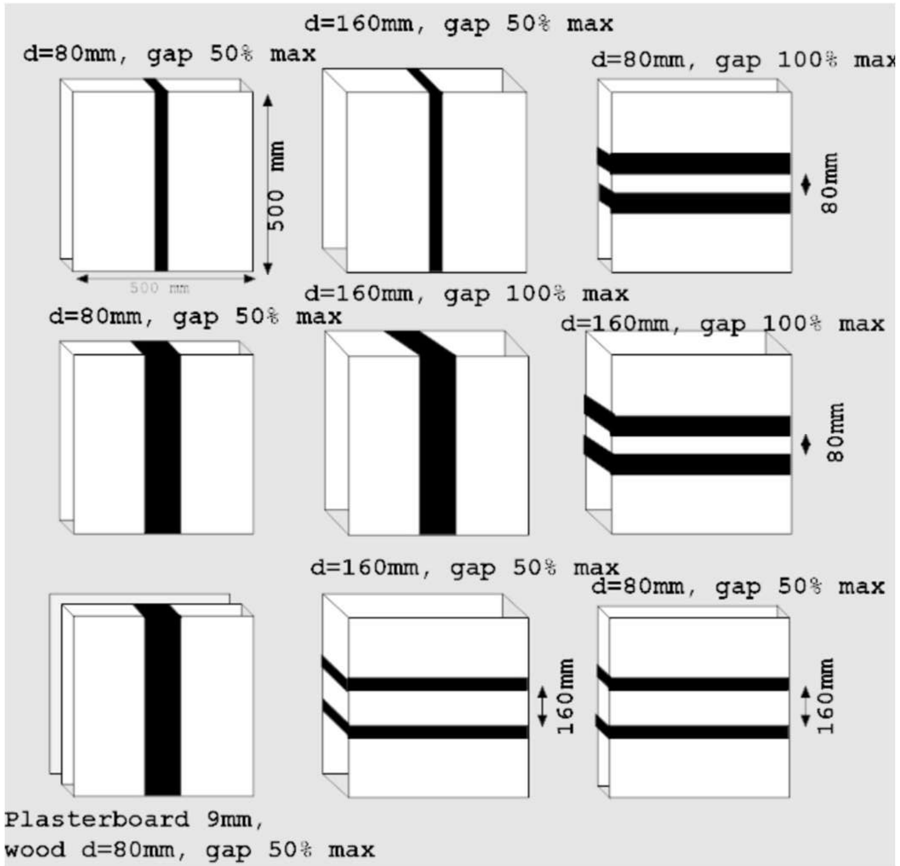


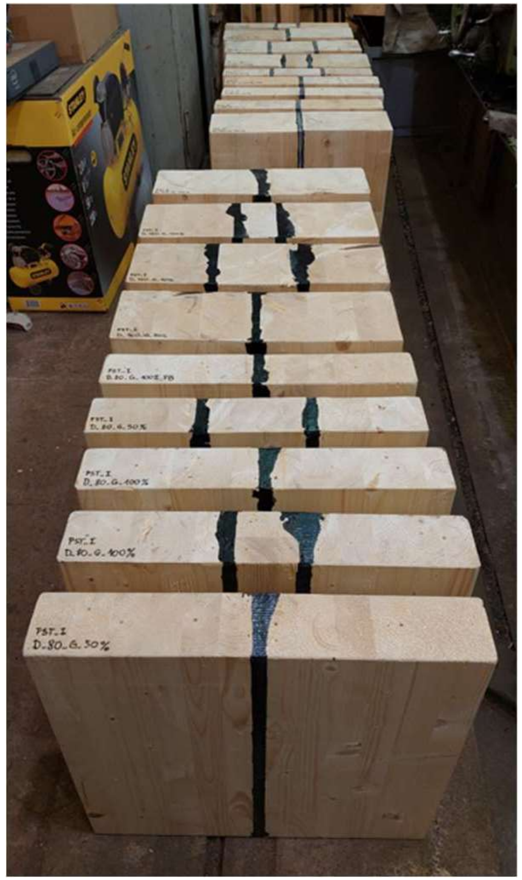
Linear thermal expansion of polyurethanes
in elevated temperatures



TG curves of polyurethanes

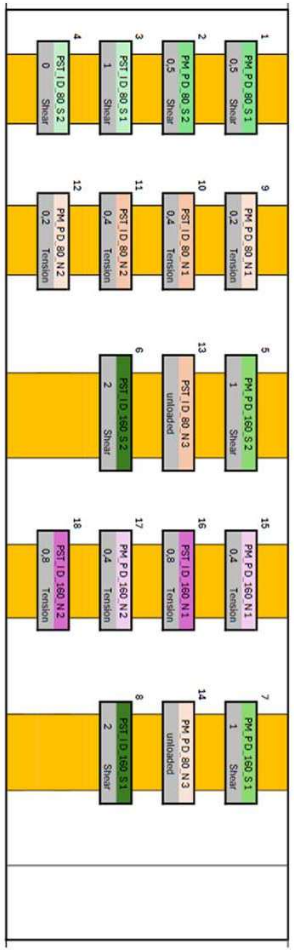
Timber specimens with polyurethane flexible adhesives tested in fire



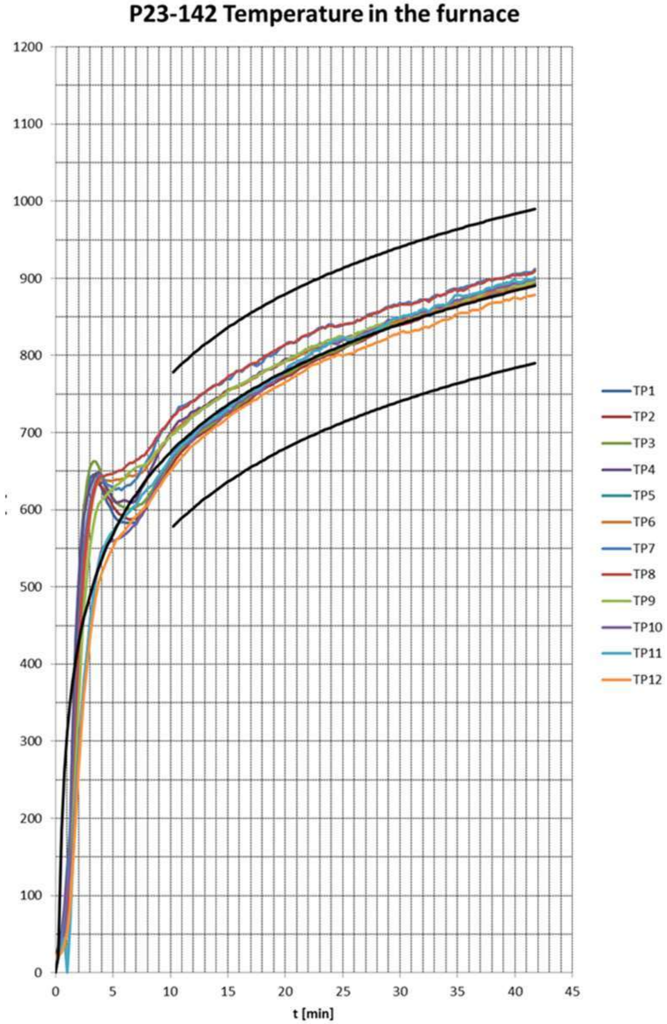


Fire resistance test

Fire resistance test of mechanically loaded samples was performed on 500 x 500 mm samples including one (**loaded in tension**) and second **(loaded in shear**) in two thicknesses: 80 and 160 mm.
Fire resistance test was performed **for 43 minutes.**

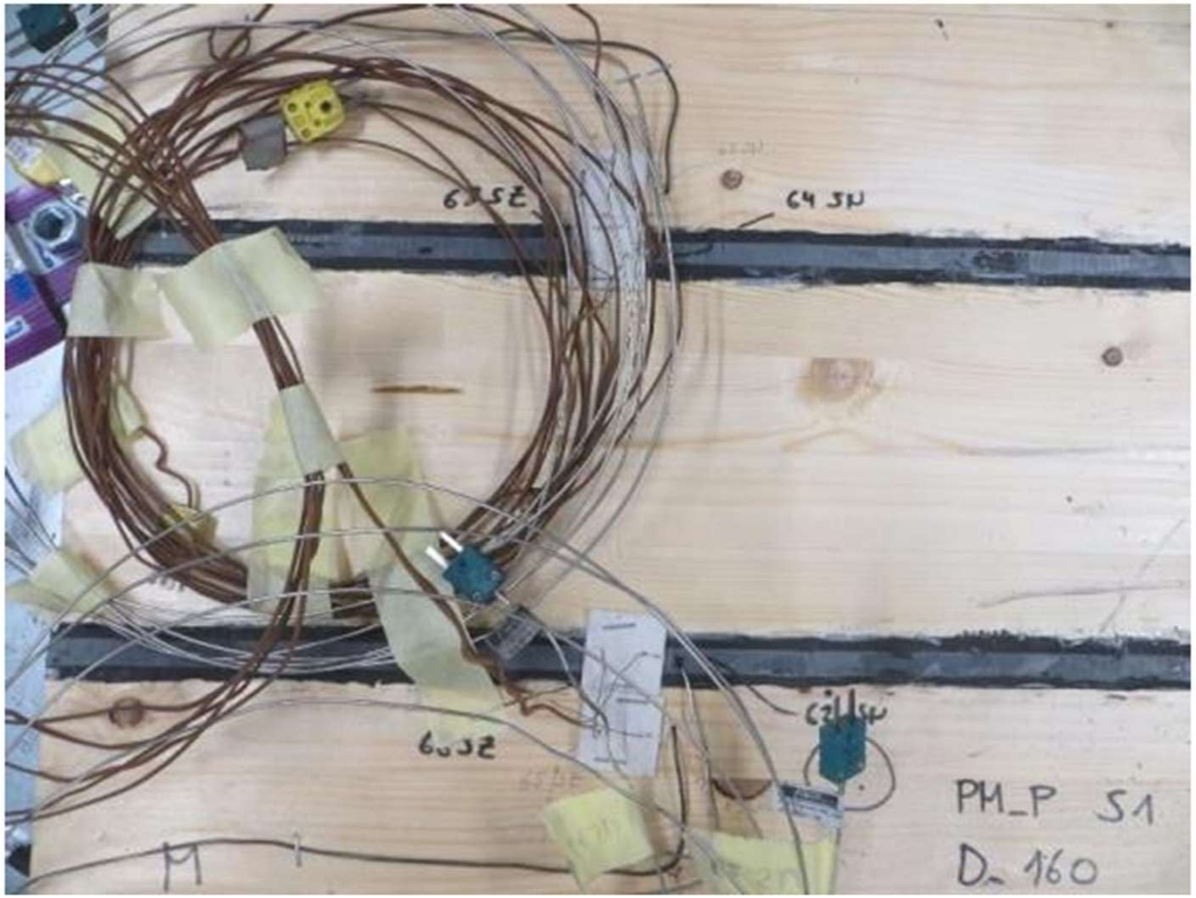
Specimen positioning on the furnace



Shear tests on specimes

Photo A6.45: Hydraulic jack positioning for mechanical shear loading before the fire resistance test
(photo archive, left: 049506d-222, right: 049506d-228)

Thermocouples



Shear test results

Table 2: Applied load.

No.	Name	Loading type	Load [tones]
7	PM_P D_160_S1	Shear	1

Photo A6.55: Specimen 7 after the fire resistance test – unexposed side (left) and exposed side (right)
(photo archive left: 049506d-501 and right:049506d-502)

P23-045 Element 7 - Temperature rise

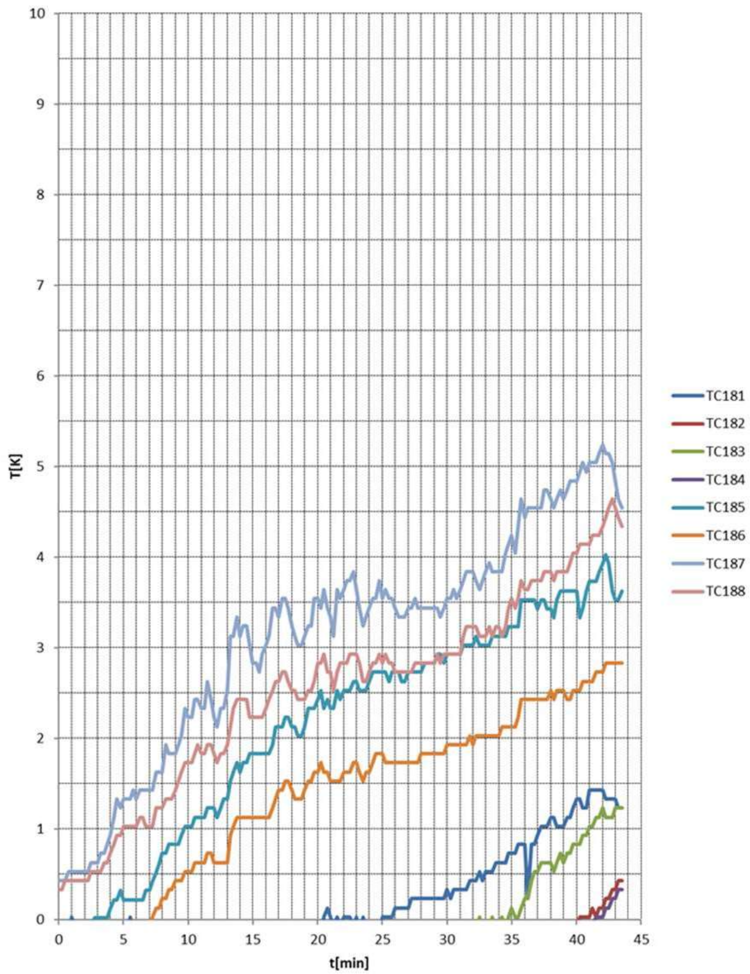


Photo A6.12: specimen no. 12 *(photo archive, left: 049506d-013, middle: 049506d-014, right: 049506d-015)*

Photo A6.22: Mechanical loading of specimen no. 12 in tension *(photo archive 049506d-069)*

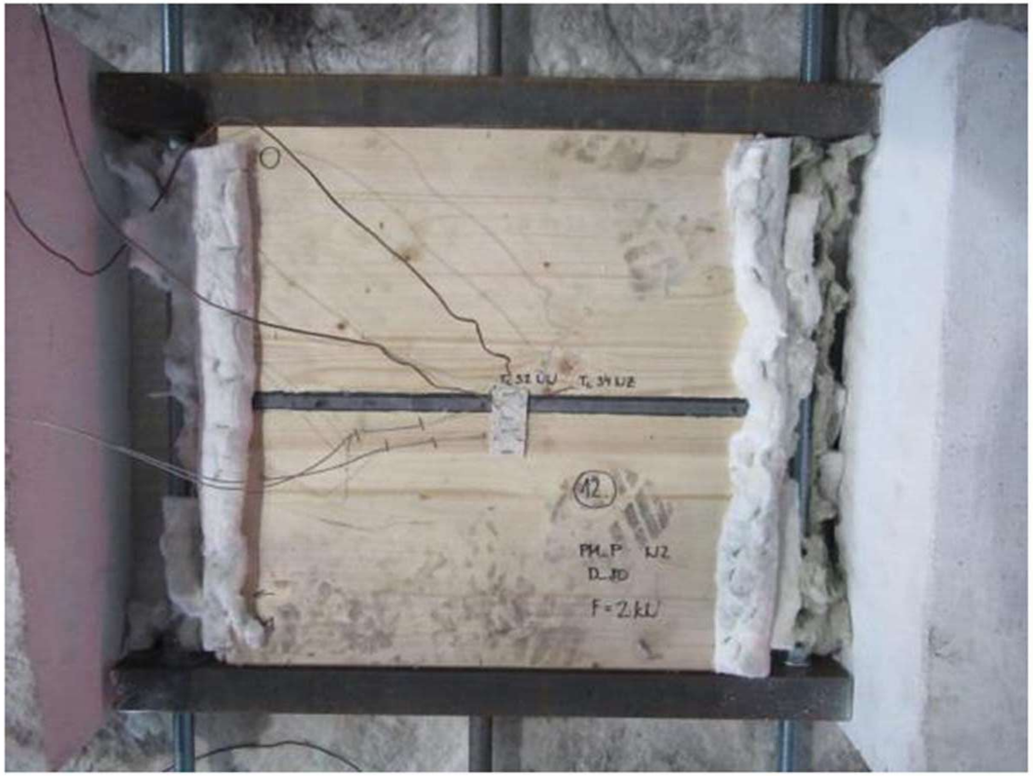


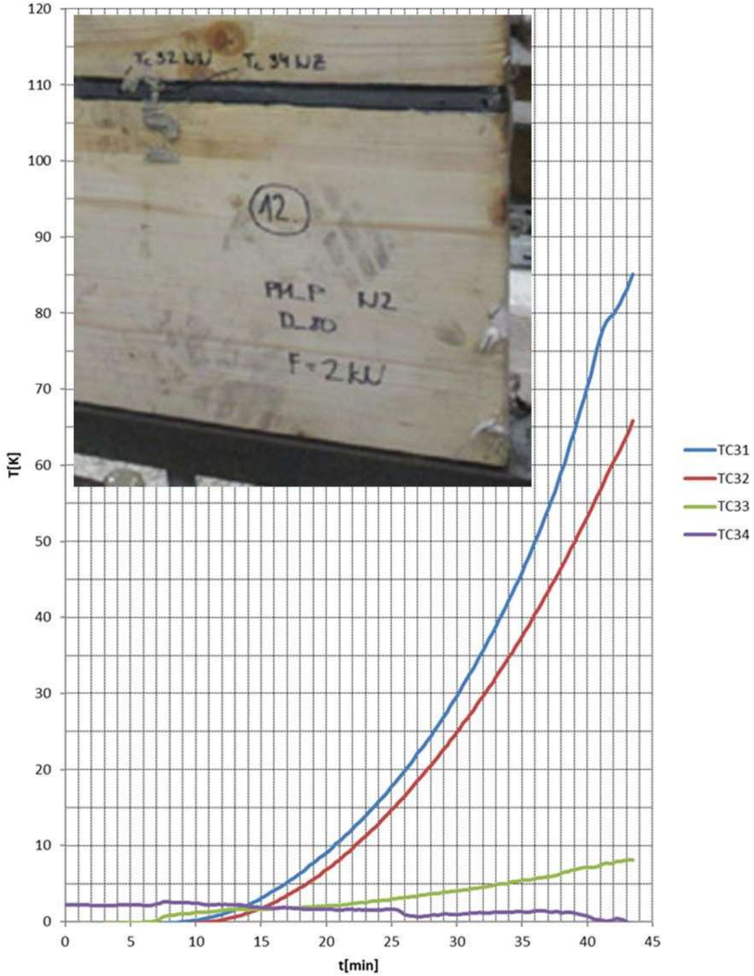
Photo A6.37: Thermocouple placement in specimen no. 12 *(photo archive 049506d-270)*

Table 2: Applied load.

No.	Name	Loading type	Load [tones]
12	PM_P D_80_N2	Tension	0.2

Photo A6.60: Specimen 12 after the fire resistance test – unexposed side (left) and exposed side (right) *(photo archive left: 049506d-447 and right:049506d-448)*

P23-045 Element 12 - Temperature rise



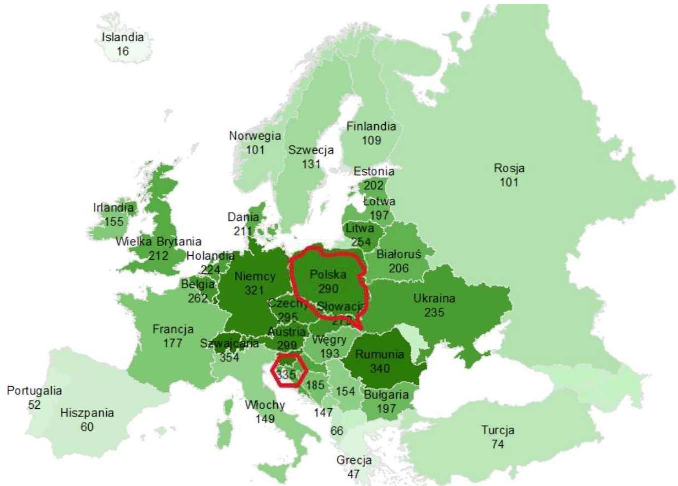
The collapses that occurred were due to exceeded shear strength of the timber and not of the flexible joint. Most of the **flexible joints withstood simultaneous mechanical and fire loading and assured tightness**.

In the fire resistance test it was noticed that timber specimens (with one or two polyurethan joints) **in case of collapse, collapsed through timber**.

The results are of research interest and show that **timber elements of stronger mechanical properties** should be used **to obtain collapse through the flexible joints** in case of fire resistance test.

Project DIAMONDS – international resesarch

- Slovenian National Building and Civil Engineering Institute
- InnoRenew CoE
- AGH University of Science and Technology
- Cracow University of Technology



NARODOWE CENTRUM NAUKI

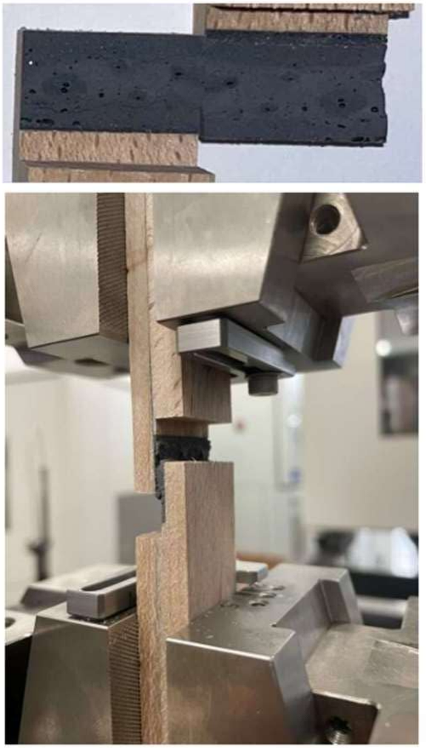
OPUS-22 (LAP)

DIAMONDS

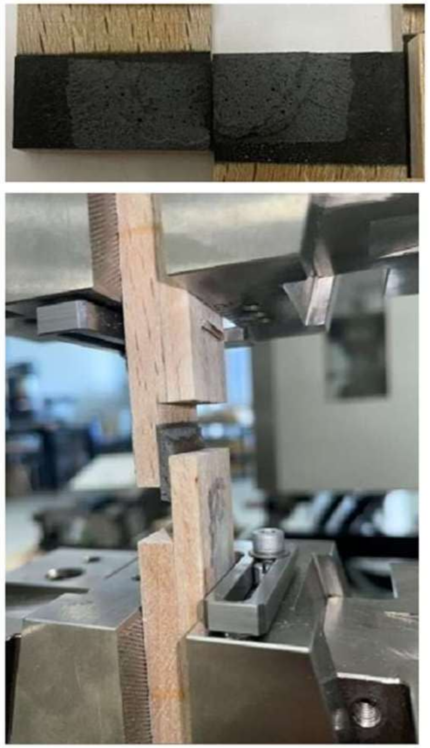
DIAMONDS - "**DIA**gnostics and **M**echanical tests **O**f aged adhesive layers used in joi**N**ts of wоо**D**en structure**S**",
Funded by the National Science Centre, Poland under the OPUS call in the Weave program,
No. 2021/43/I/ST8/00554

Presentation of Klaudia Śliwa-Wieczorek

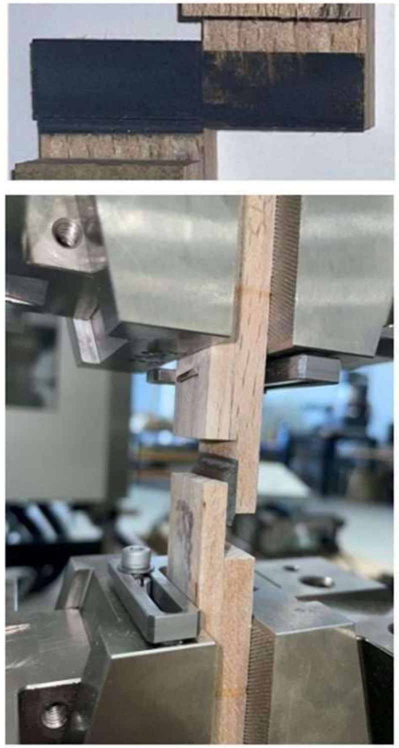
LAP SHEAR TESTING:FAILURES IN ADHESIVES



PS



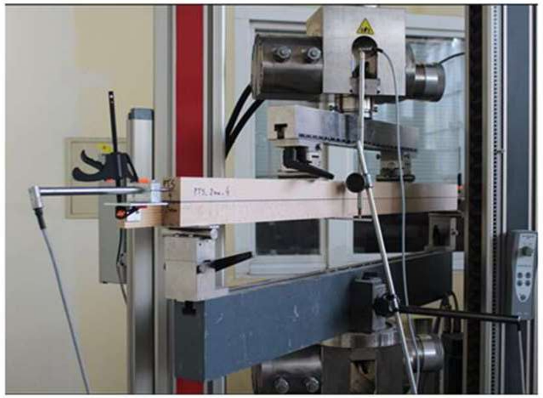
PST



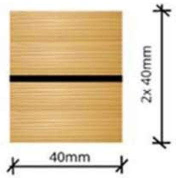
PTS

Presentation of Klaudia Śliwa-Wieczorek

BENDING TESTS:

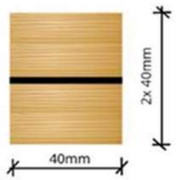


t=dx



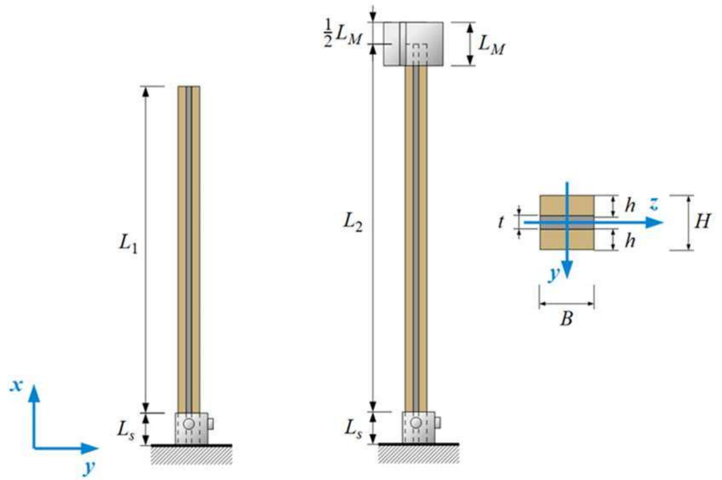
t=dx	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	9	9	9	9
time "1"	9	9	9	9
time "2"	9	9	9	9
	total:	**108**	**samples**	

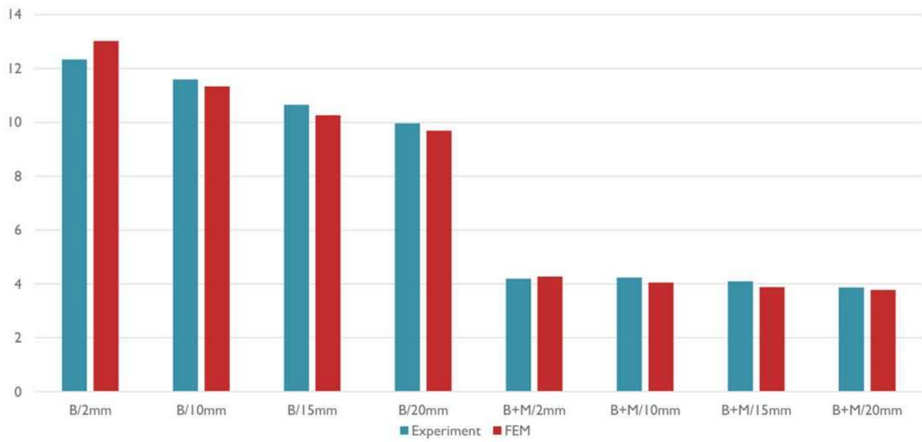
t=2mm



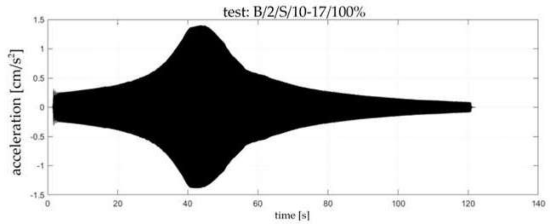
t=2mm	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	0	9	9	9
time "1"	0	9	9	9
time "2"	0	9	9	9
	total:	**108**	**samples**	

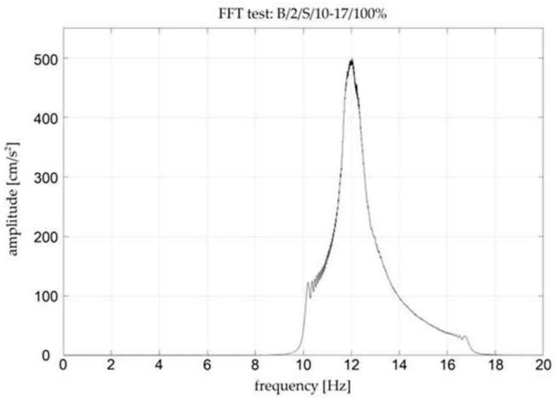
Poster of Jarosław Chełmecki





Shake table excitation

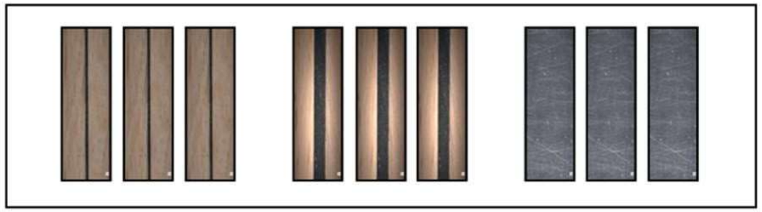




Poster of Teresa Stryszewska

Cracow University of Technology 80th Anniversary

POLYURETHANE PS, PM



TESTS:

- OPTICAL MICROSCOPE
- SCANNING MICROSCOPE
- INFARED ANALYSIS

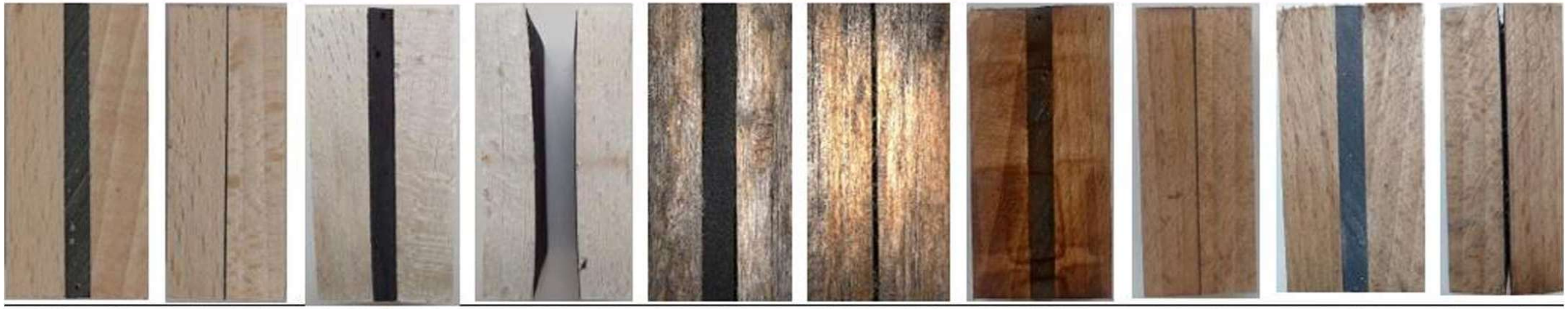
- NATURAL WEATHERING (one year)
- ACCELERATED WEATHERING UV radiation (5000 h)
- CHEMICAL INFLUENCE
  - Salt breeze (1000h)
  - Water fog (1000h)

TESTS:

- OPTICAL MICROSCOPE
- SCANNING MICROSCOPE
- INFARED ANALYSIS

Poster of Teresa Stryszewska

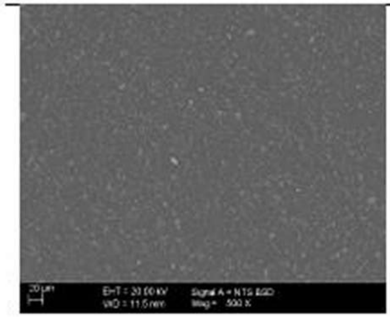
Photos of samples of wood glued with PS polyurethane before and after ageing



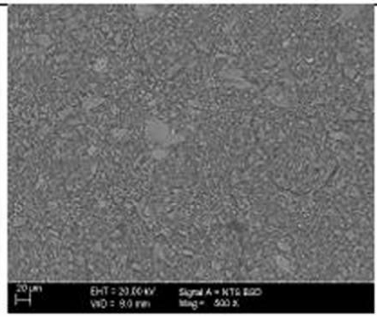
layer 2 mm, reference	layer dx, reference	layer 2 mm, after accelerated wethering in	layer dx, after accelerated wethering in UV	layer 2 mm, after natural weathering	layer dx, after n atural weathering	layer 2 mm, after water fog	layer dx, after water fog	layer 2 mm, after Salt fog	layer dx, after Salt fog

Photos of PS polyurethane samples before and after aging

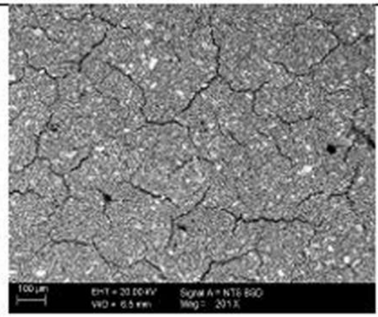
reference	after accelerated wethering in UV	after natural weathering	after water fog	after salt fog



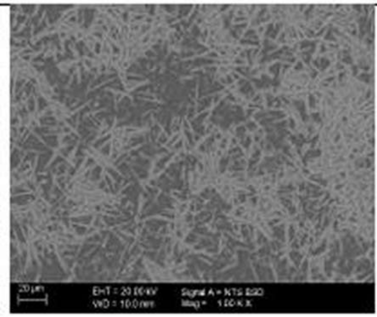
reference,
mag. 200x,
SEM image



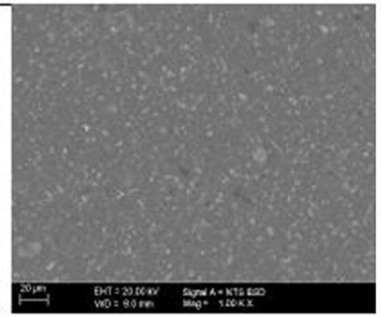
after accelerated weathering
UV, mag. 200x,
SEM image



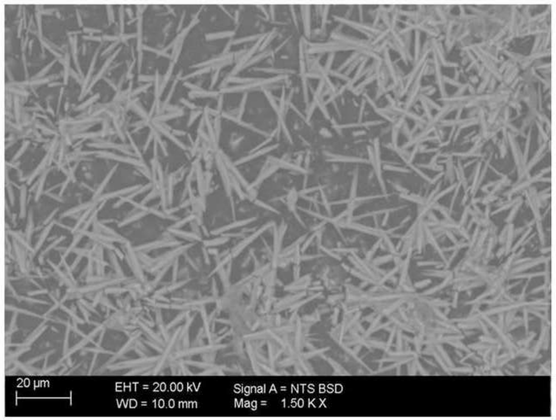
after natural weathering,
mag. 200x,
SEM image

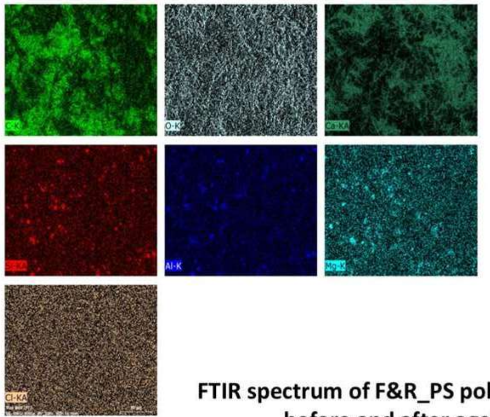


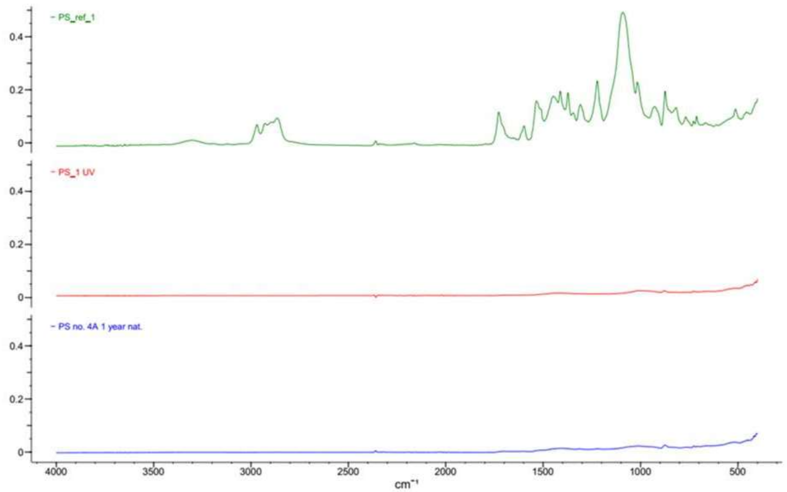
after water fog, mag. 1000x,
SEM image



after salt fog, mag. 1000x,
SEM image

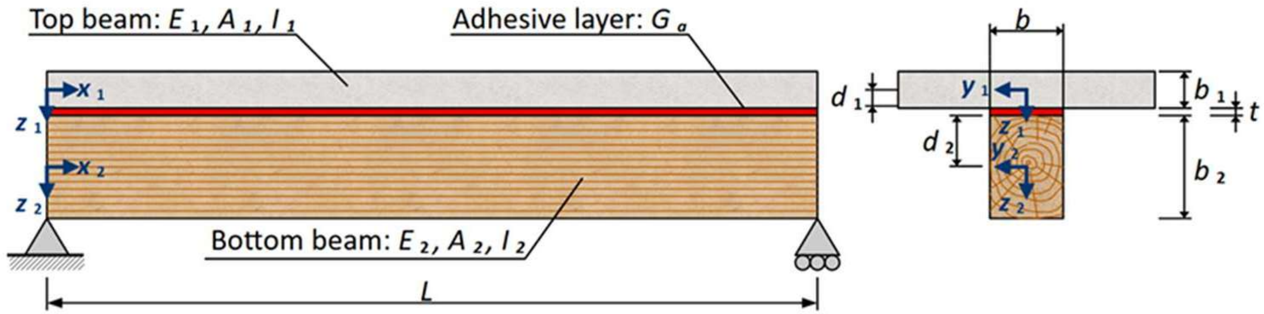


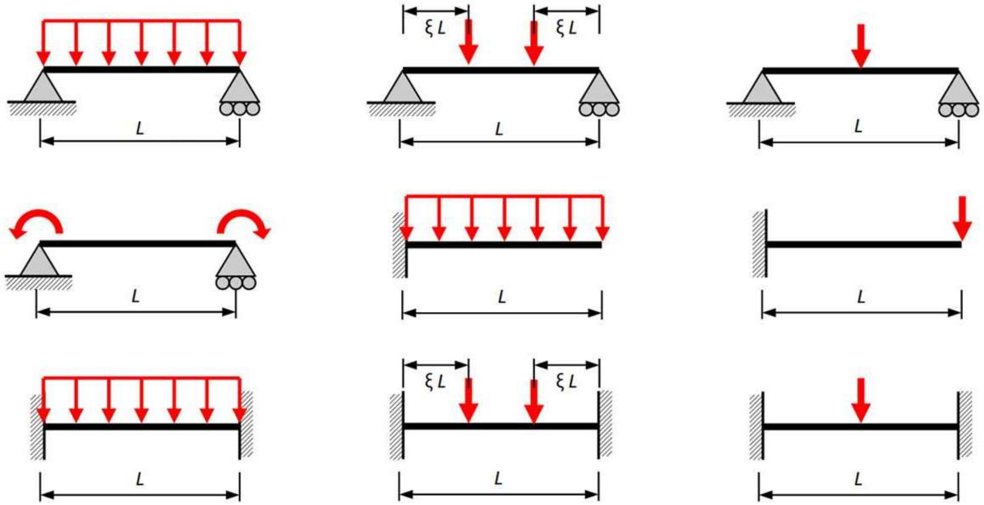


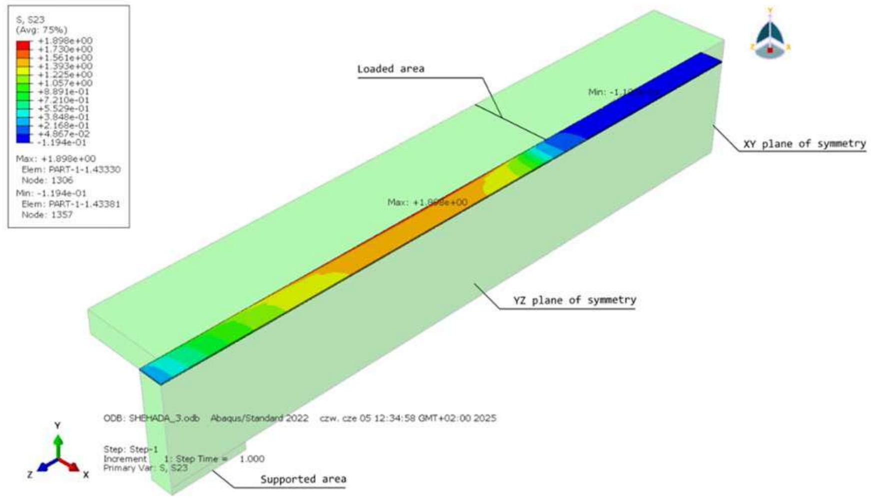


FTIR spectrum of F&R_PS polyurethane
before and after ageing

Poster of Paweł Szeptyński







Poster of Paweł Szeptyński

Volkersen shear lag theory

$$\begin{cases} \dfrac{d^2\tilde{u}_1}{d\chi^2} + \beta\left[\left(\tilde{u}_2 - \tilde{u}_1\right) + \alpha\dfrac{d\tilde{w}}{d\chi}\right] = 0 \\ \dfrac{d^2\tilde{u}_2}{d\chi^2} - \gamma\left[\left(\tilde{u}_2 - \tilde{u}_1\right) + \alpha\dfrac{d\tilde{w}}{d\chi}\right] = 0 \\ \dfrac{d^4\tilde{w}}{d\chi^4} = \varepsilon + \delta\left[\left(\dfrac{d\tilde{u}_2}{d\chi} - \dfrac{d\tilde{u}_1}{d\chi}\right) + \alpha\dfrac{d^2\tilde{w}}{d\chi^2}\right] \end{cases}$$

coupling terms

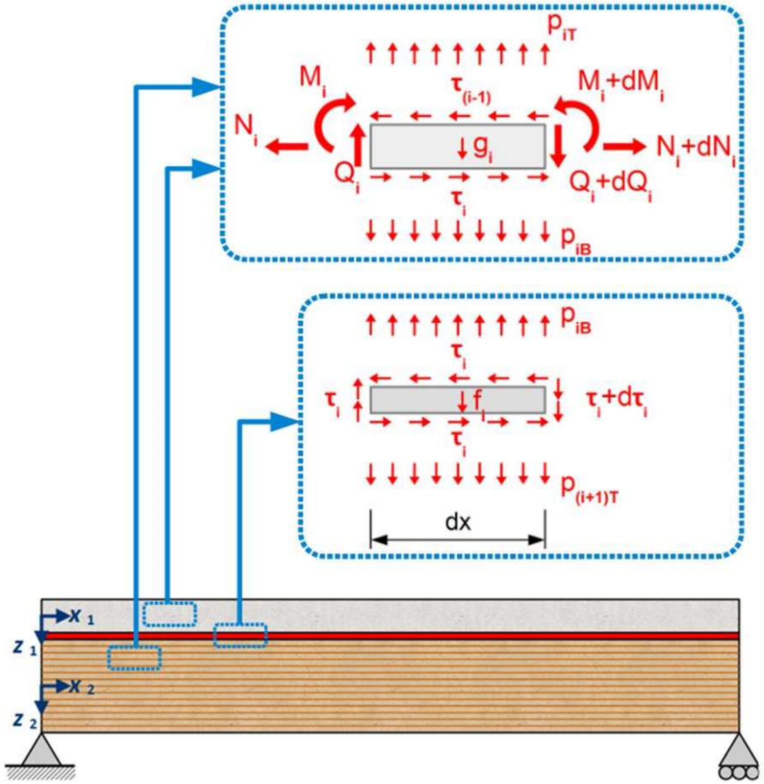
Bernoulli – Euler beam theory

SIMILARITY NUMBERS

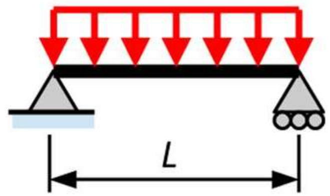
$$\alpha = \frac{d_1+d_2}{L} \qquad \beta = \frac{G_a L^2 b}{E_1 A_1 t} \qquad \gamma = \frac{G_a L^2 b}{E_2 A_2 t}$$

$$\varepsilon = \frac{L^3(q+A_1 g_1+A_2 g_2+b t g_a)}{E_1 I_1+E_2 I_2} \qquad \delta = \frac{G_a L^3 b(d_1+d_2+t)}{t(E_1 I_1+E_2 I_2)}$$

$$\lambda=\sqrt{\alpha\delta+\beta+\gamma}$$



Poster of Paweł Szeptyński



Deflection in the middle of the span:

$$w_{\max} = \varepsilon L \frac{768\alpha\delta e^{\frac{\lambda}{2}} + (e^{\lambda}+1)\left[5\lambda^4(\beta+\gamma) + 48\alpha\delta(\lambda^2-8)\right]}{384\lambda^6(e^{\lambda}+1)}$$

Normal stress distribution in the upper adherend in the middle of the span:

$$\sigma_{1,span} = \varepsilon E_1 \left[-\alpha\beta\left(\frac{2e^{\frac{\lambda}{2}}}{\lambda^4(e^{\lambda}+1)} + \frac{\lambda^2-8}{8\lambda^4}\right) + \frac{z_1}{L}\left(\frac{\alpha\delta\left(e^{\frac{\lambda}{2}}-1\right)^2}{\lambda^4(e^{\lambda}+1)} + \frac{\beta+\gamma}{8\lambda^2}\right)\right]$$

Normal stress distribution in the bottom adherend in the middle of the span:

$$\sigma_{2,span} = \varepsilon E_2 \left[\alpha\gamma\left(\frac{2e^{\frac{\lambda}{2}}}{\lambda^4(e^{\lambda}+1)} + \frac{\lambda^2-8}{8\lambda^4}\right) + \frac{z_2}{L}\left(\frac{\alpha\delta\left(e^{\frac{\lambda}{2}}-1\right)^2}{\lambda^4(e^{\lambda}+1)} + \frac{\beta+\gamma}{8\lambda^2}\right)\right]$$

Maximal shear stress in the supported cross-section:

$$\tau_{\max} = \varepsilon\alpha G_a L \frac{\lambda(e^{\lambda}+1) - 2(e^{\lambda}-1)}{2t\lambda^3(e^{\lambda}+1)}$$

Conclusions

Innovative PUFJ and FRPU are ready for commercialization in buildings' envelopes, significantly improving connections in seismic and strong wind areas and under fire exposure

Application of flexible PU adhesives in beech wood connections opens new promissing opportunities for structural applications in wooden elements, but requires further research on large scale specimens

PU flexible adhesives in timber structures are new generation bonding solution

Thank you for your attention!

MEZeroE project is a project receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 953157.

DIAMONDS - "**DIA**gnostics and **M**echanical tests **O**f aged adhesive layers used in joi**N**ts of woo**D**en structure**S**",
Funded by the National Science Centre, Poland under the OPUS call in the Weave program,
No. 2021/43/I/ST8/00554